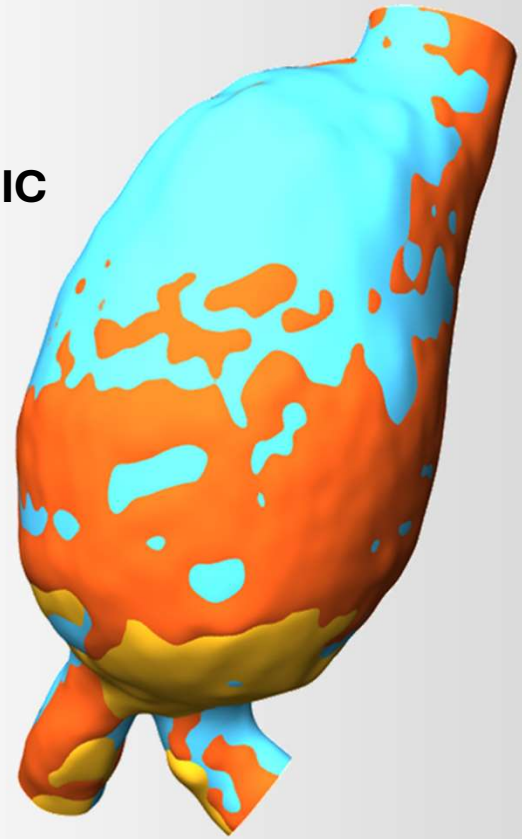
VPH2022
virtual physiological human conference

IMPACT OF IMAGE SEGMENTATION VARIABILITY ON HEMODYNAMIC PREDICTIONS OF FLOW QUANTITIES IN AAA

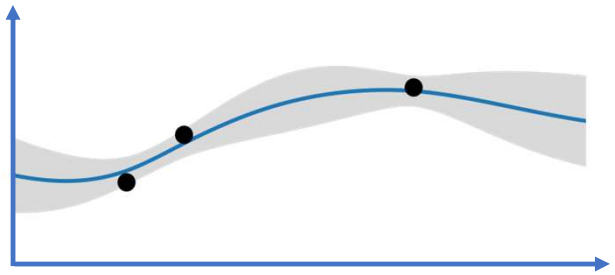
Antonio Martínez[1,4], Daan Jongerius[2], Marc Horner[3], Leonardo Geronzi[1], Eirini Kardampiki[1], Marco Evangelos Biancolini[1]

1. University of Rome "Tor Vergata", Italy;
2. Eindhoven University of Technology, Netherlands;
3. Ansys, Inc, Evanston, IL, USA; 4. Ansys, Inc, Lyon, France



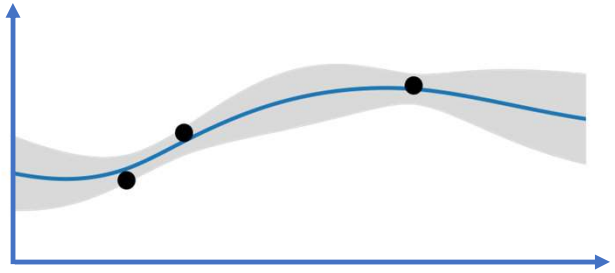
Background

- In order to incorporate computational models into the clinical industry, a thorough understanding on the uncertainty introduced by the model inputs is mandatory.



Background

- In order to incorporate computational models into the clinical industry, a thorough understanding on the uncertainty introduced by the model inputs is mandatory.
- Introducing an in-silico product on the market requires FDA or EU MDR approval, which is obtained after a verification and validation procedure. This process requires stablishing tolerances and deviations margins on the software's output.



Uncertainty sources

Uncertainty sources

- **Data acquisition**

Spatial resolution

Temporal resolution

Artifacts

Noise

Uncertainty sources

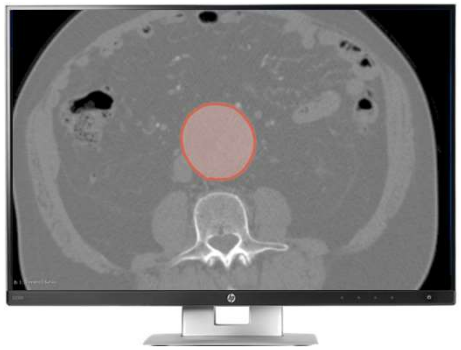
- **Data acquisition**

Spatial resolution

Temporal resolution

Artifacts

Noise



- **Data preprocessing**

Segmentation

Smoothing

Filtering

Uncertainty sources

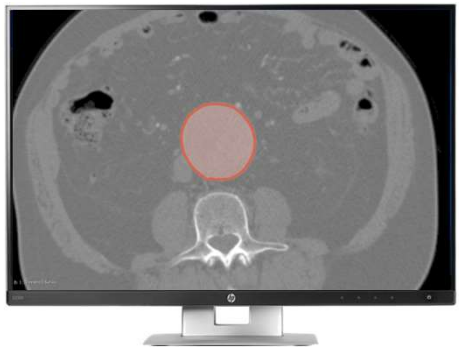
Data acquisition

Spatial resolution

Temporal resolution

Artifacts

Noise

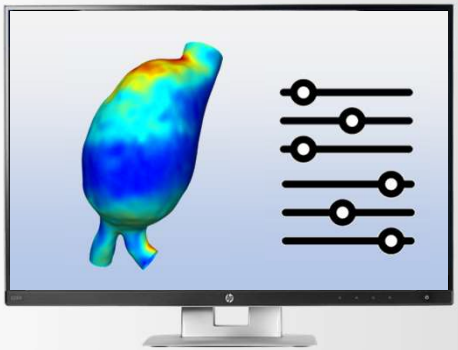


Data preprocessing

Segmentation

Smoothing

Filtering



Model setup

Turbulence model

Material models

Boundary conditions

CFD-FEM-FSI

Uncertainty sources

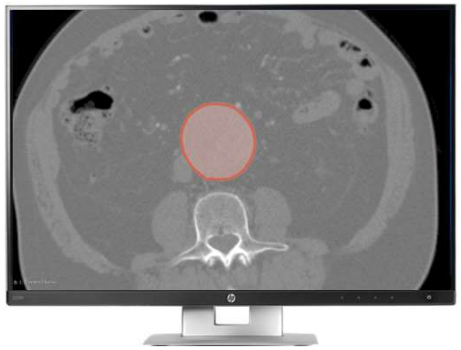
Data acquisition

Spatial resolution

Temporal resolution

Artifacts

Noise

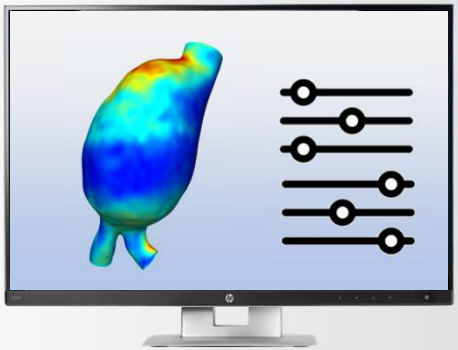


Data preprocessing

Segmentation

Smoothing

Filtering



Model setup

Turbulence model

Material models

Boundary conditions

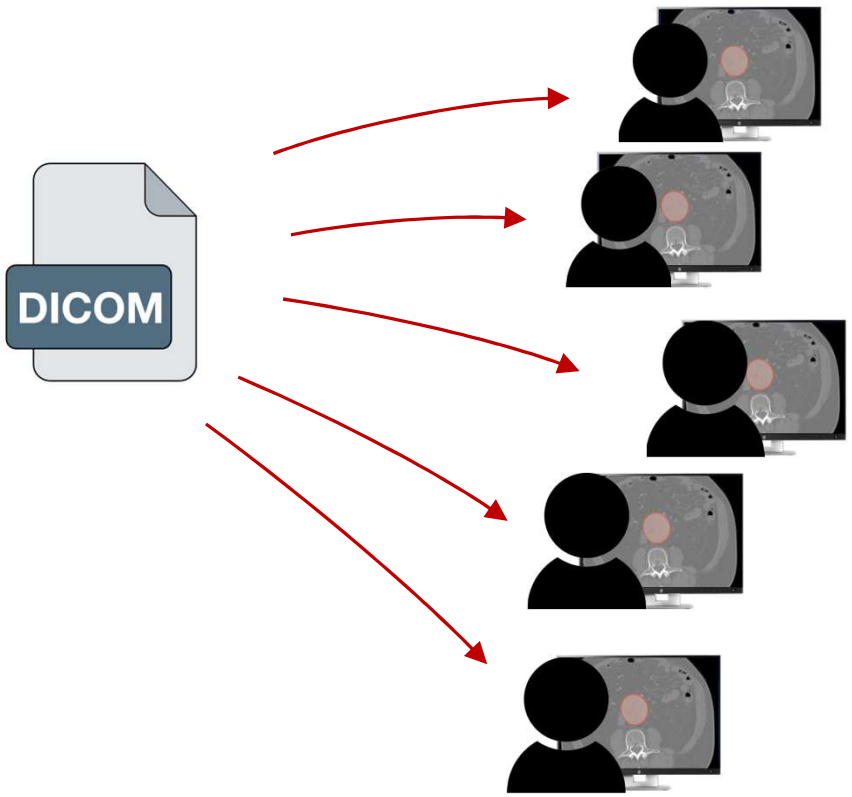
CFD-FEM-FSI

Workflow

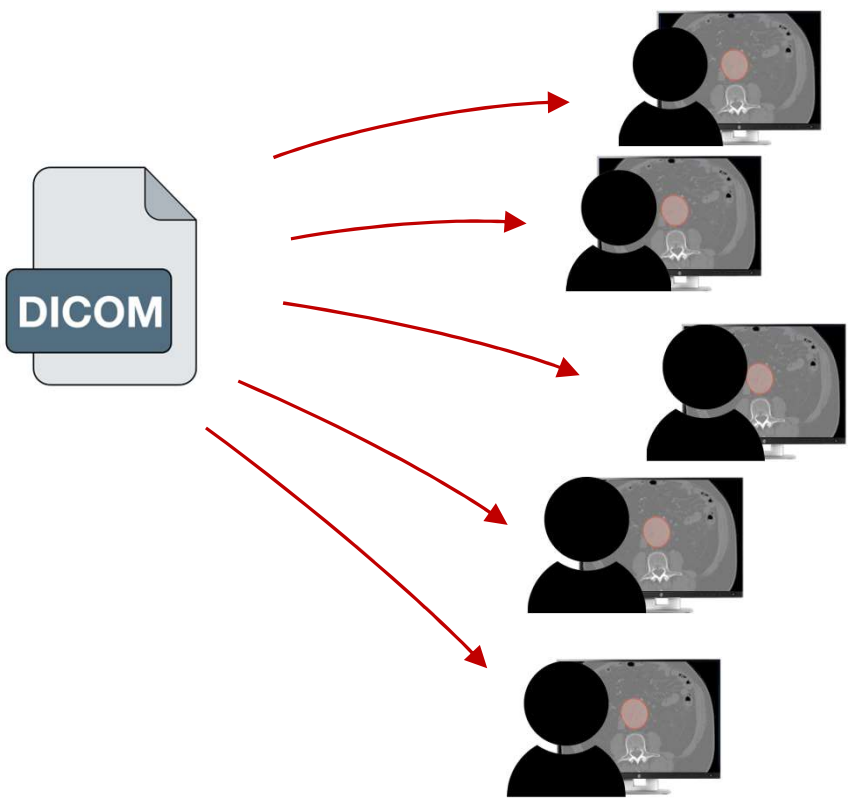
Workflow

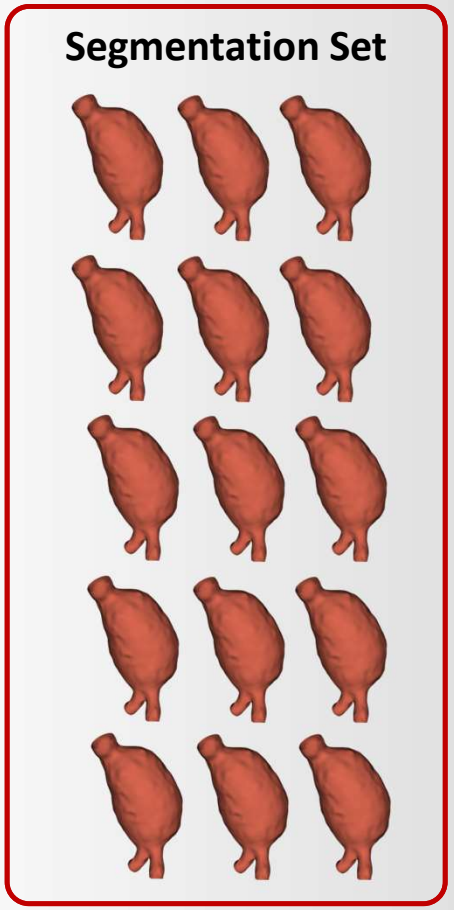
- CT Scan segmented by 15 independent groups.
- Quantification of the geometric variability.
- Run steady and transient CFD analyses.
- Quantification of the variability on hemodynamic variables.

Segmentation

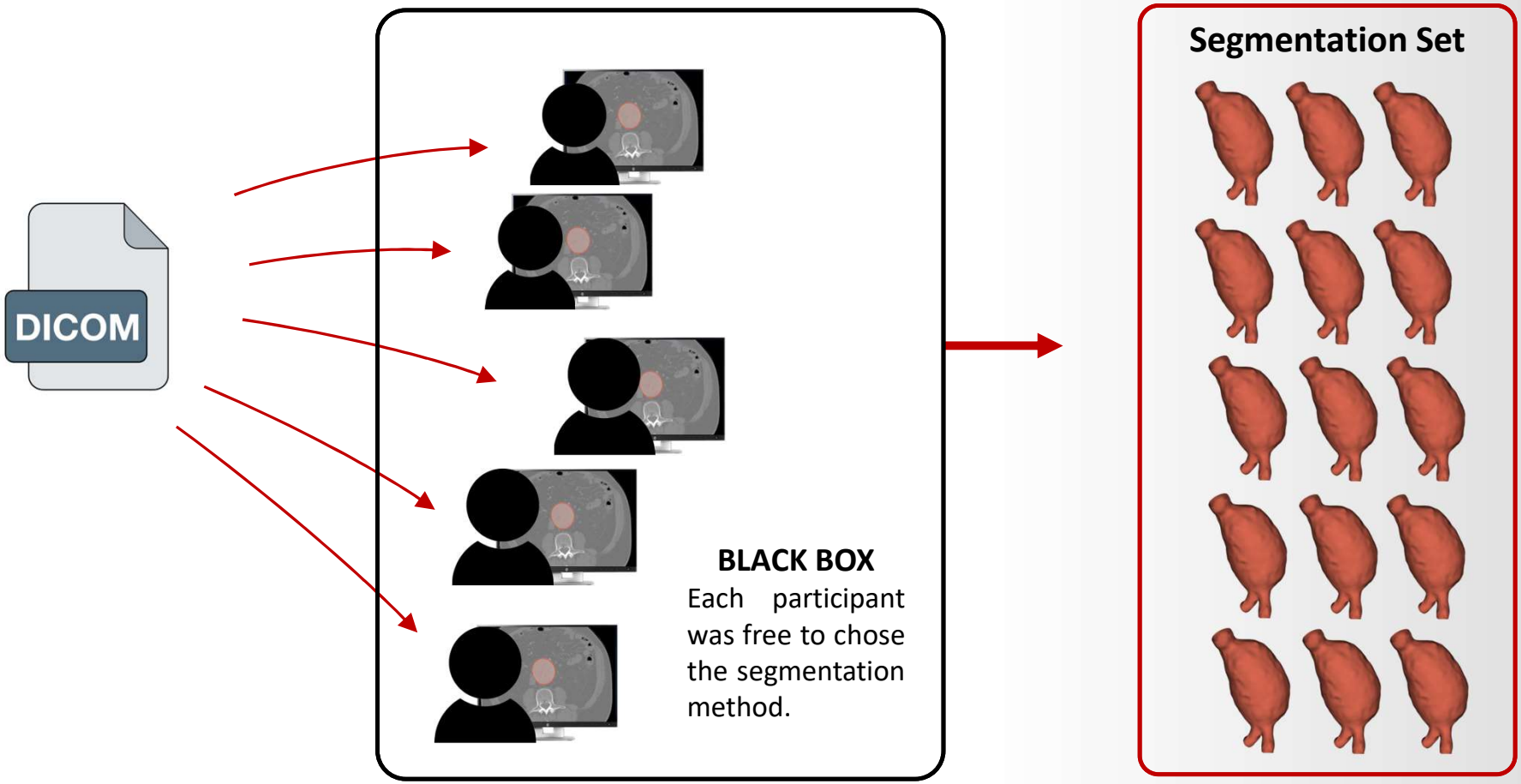


Segmentation

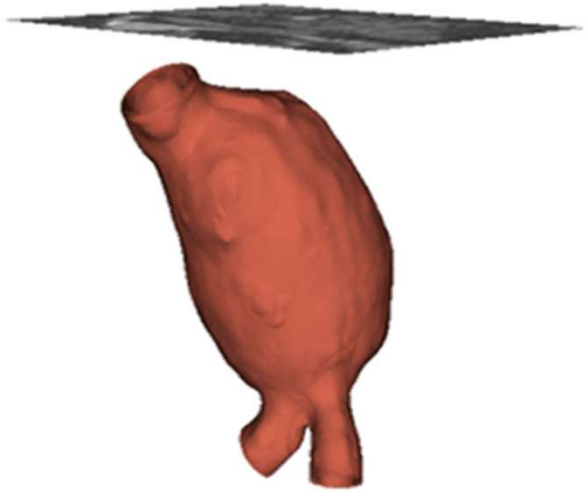


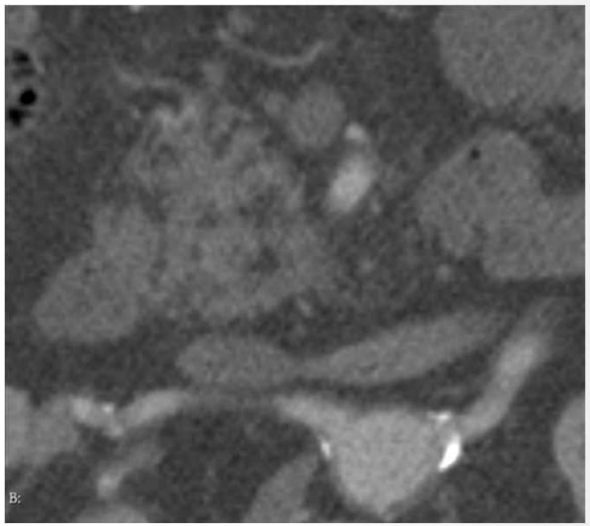


Segmentation



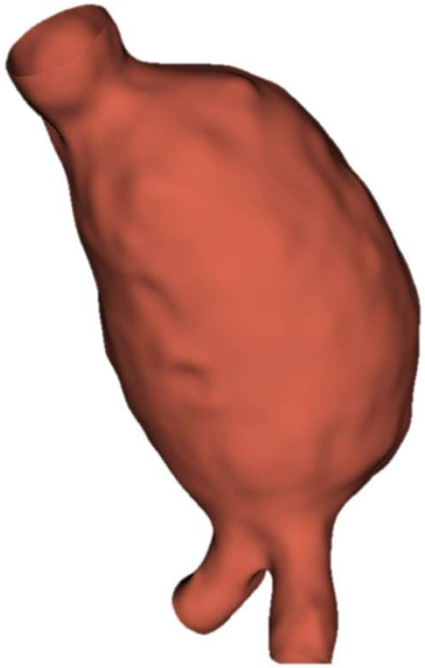
Segmentation



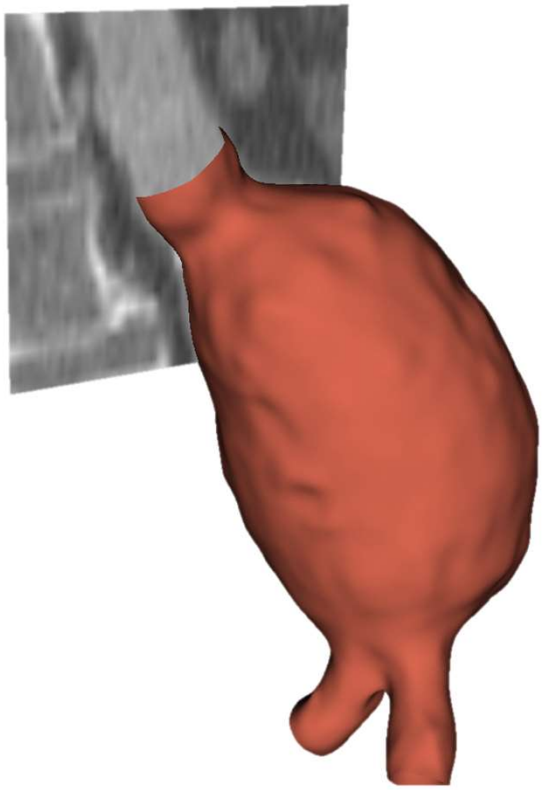


Voxel size = [0.824, 0.824, 2.5] mm

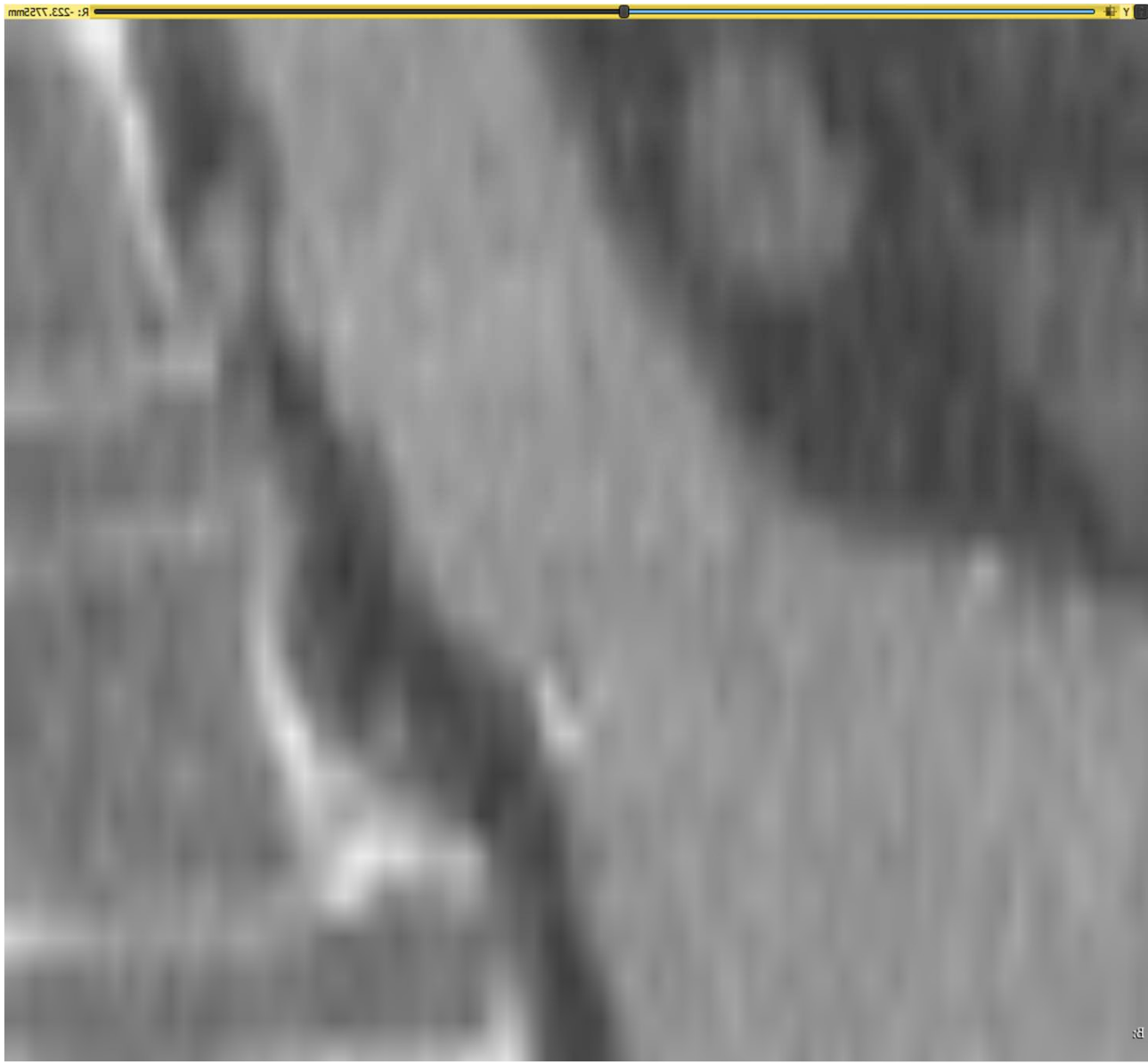
Segmentation



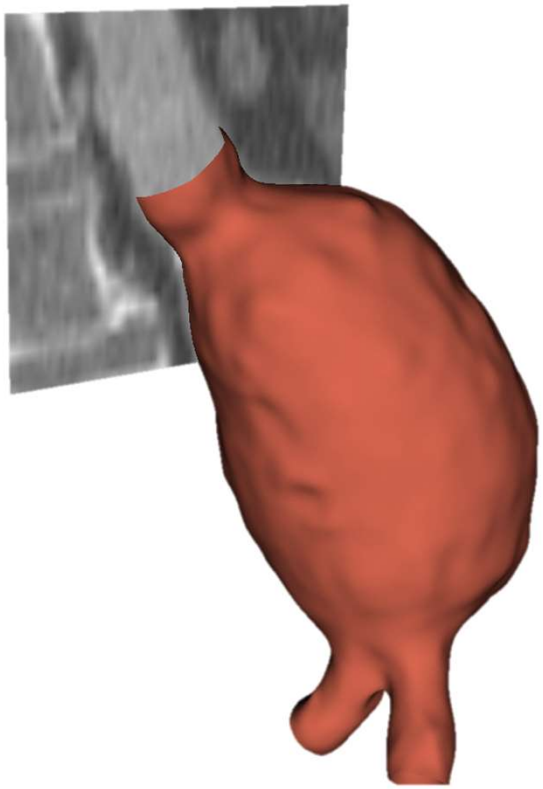
Segmentation

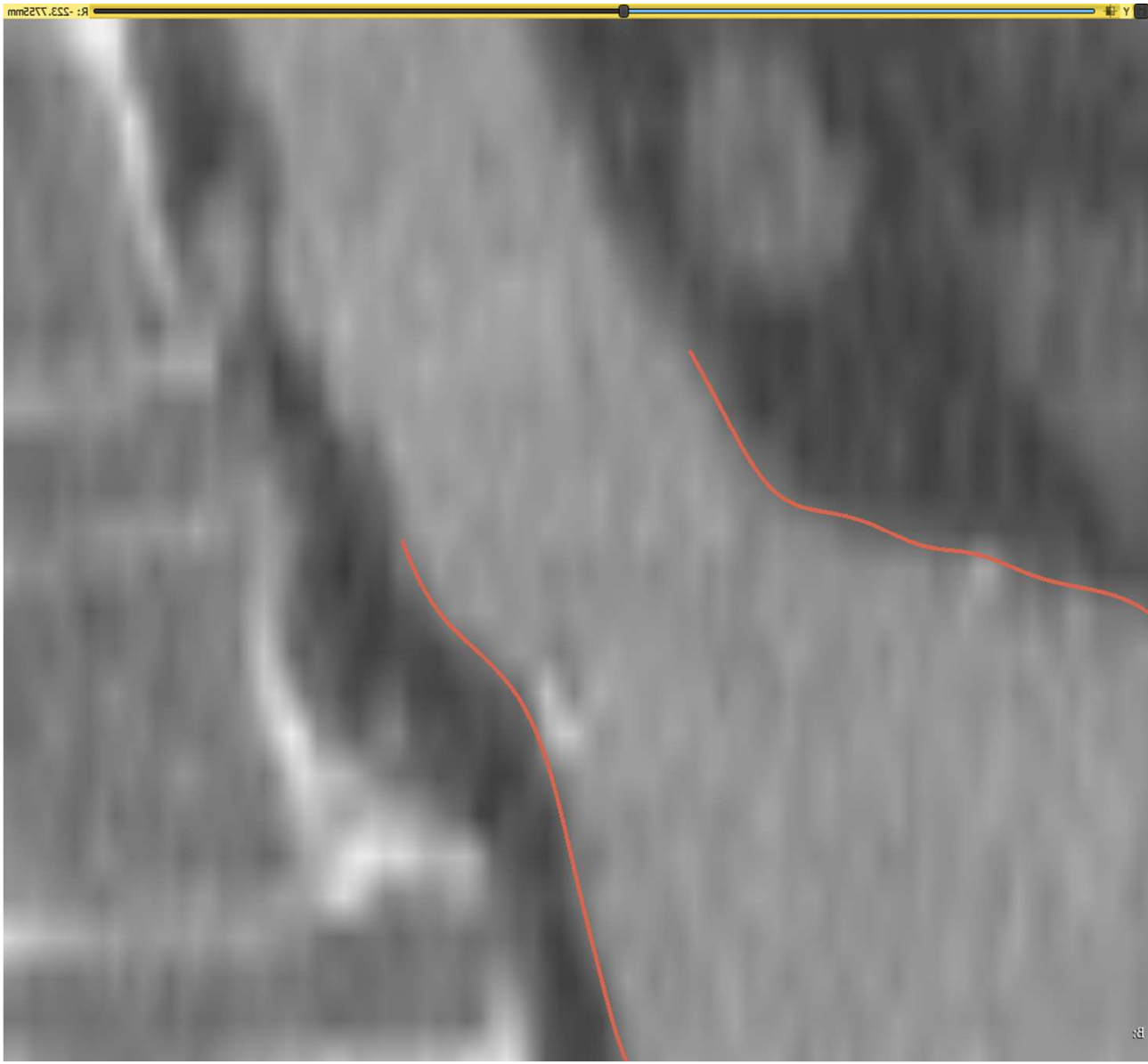


Voxel size = [0.824, 0.824, **2.5**] mm

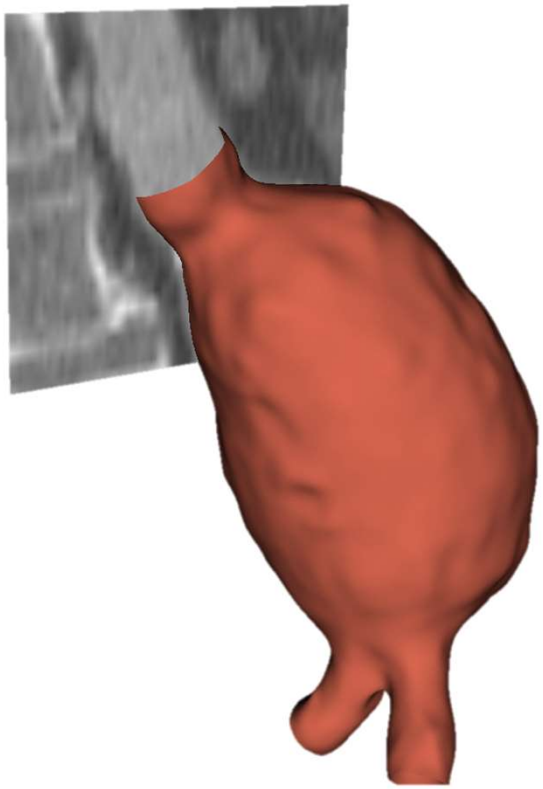


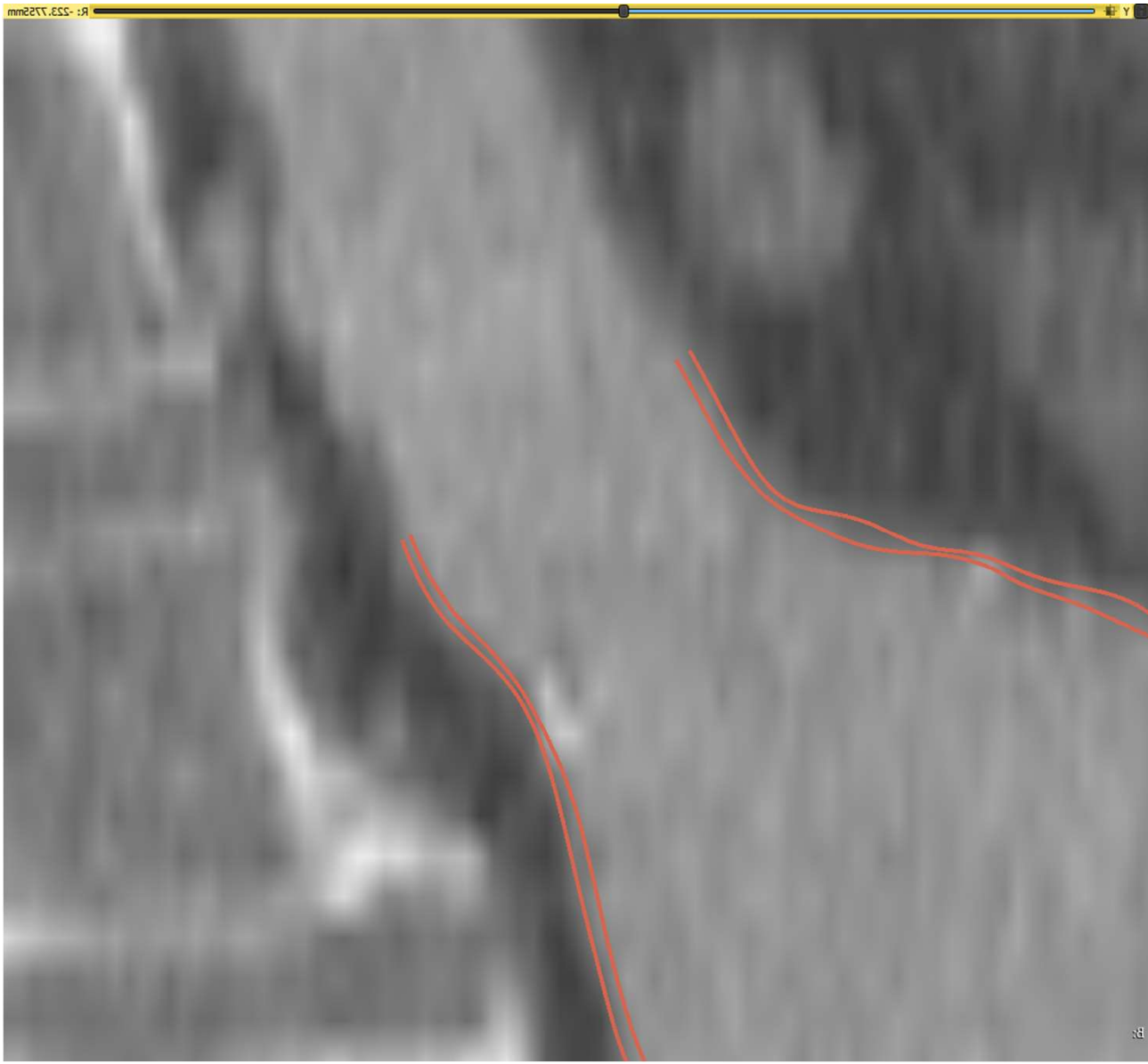
Segmentation



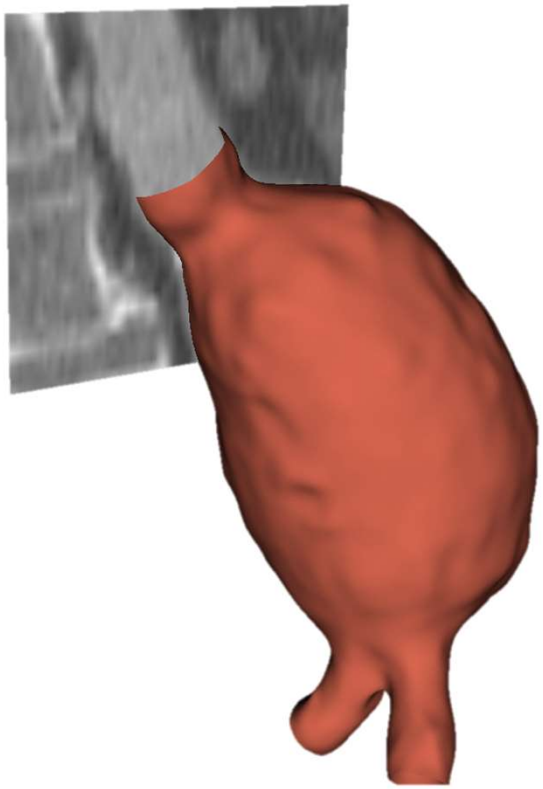


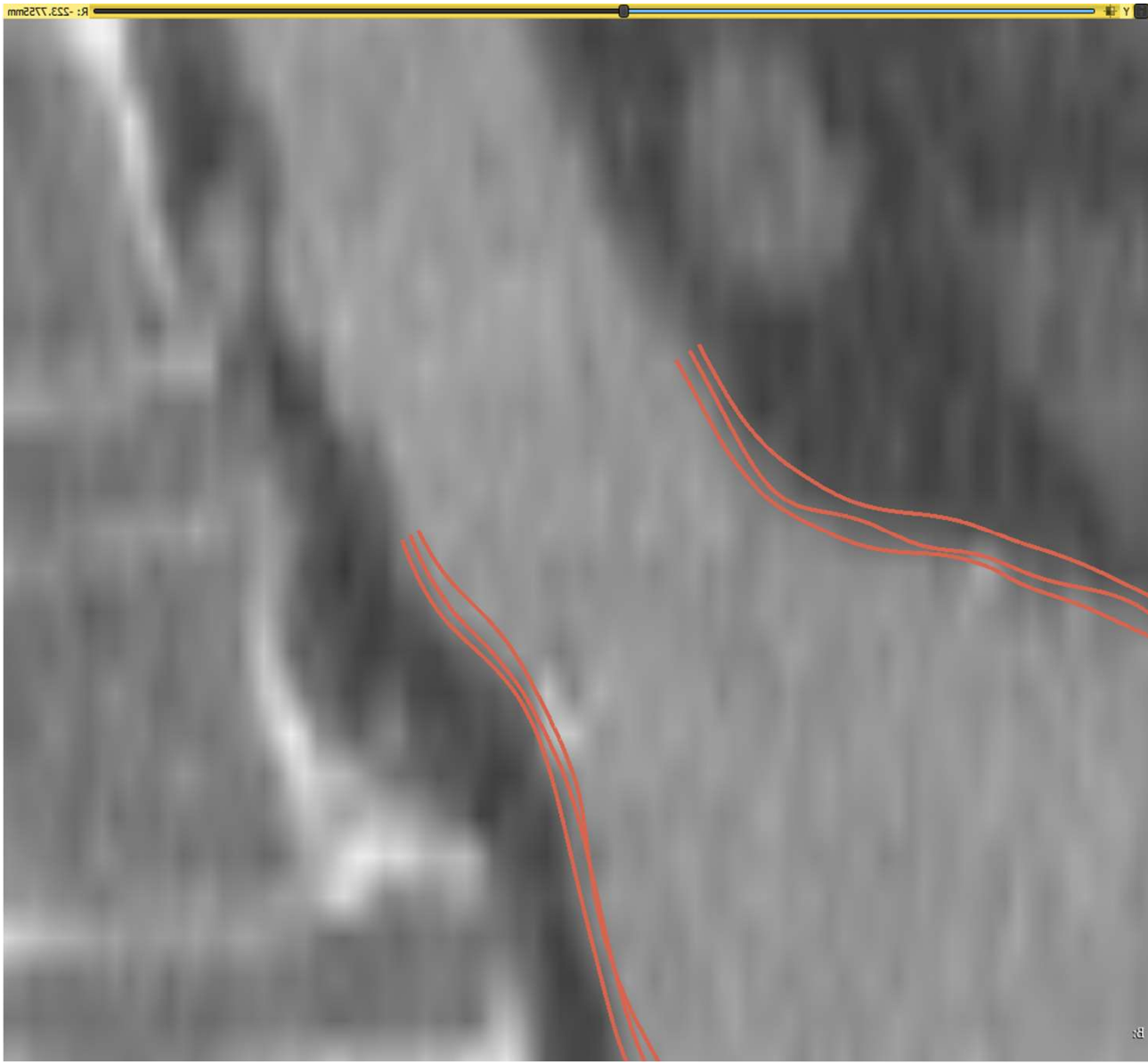
Segmentation



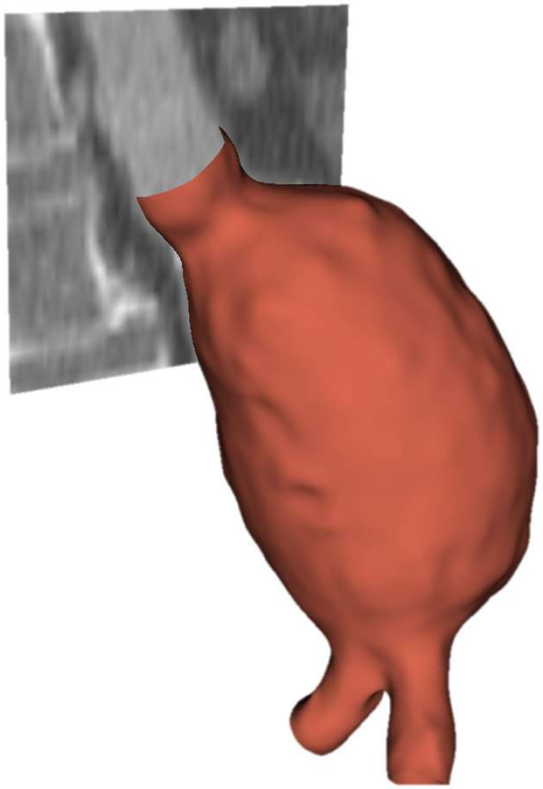


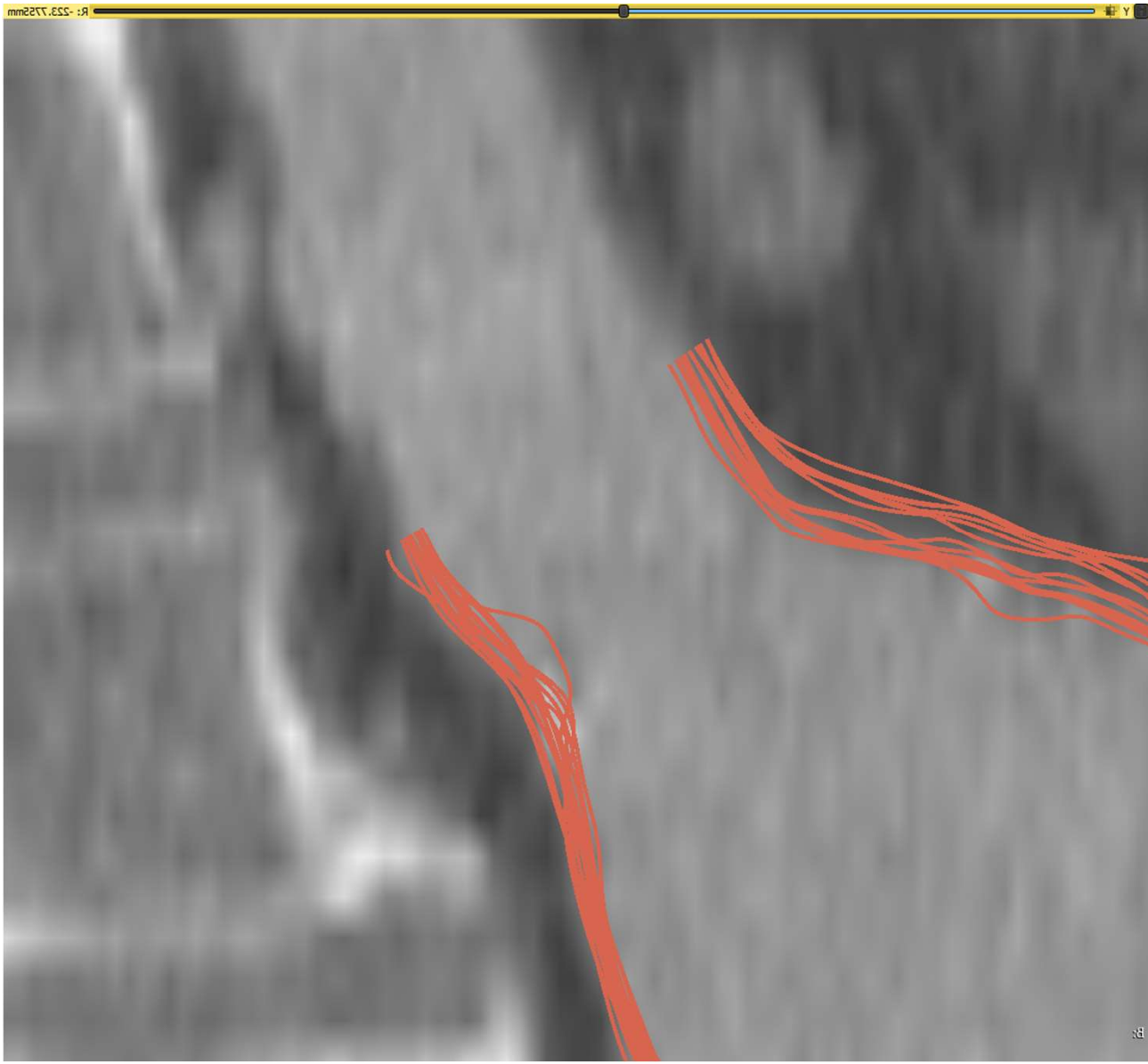
Segmentation





Segmentation

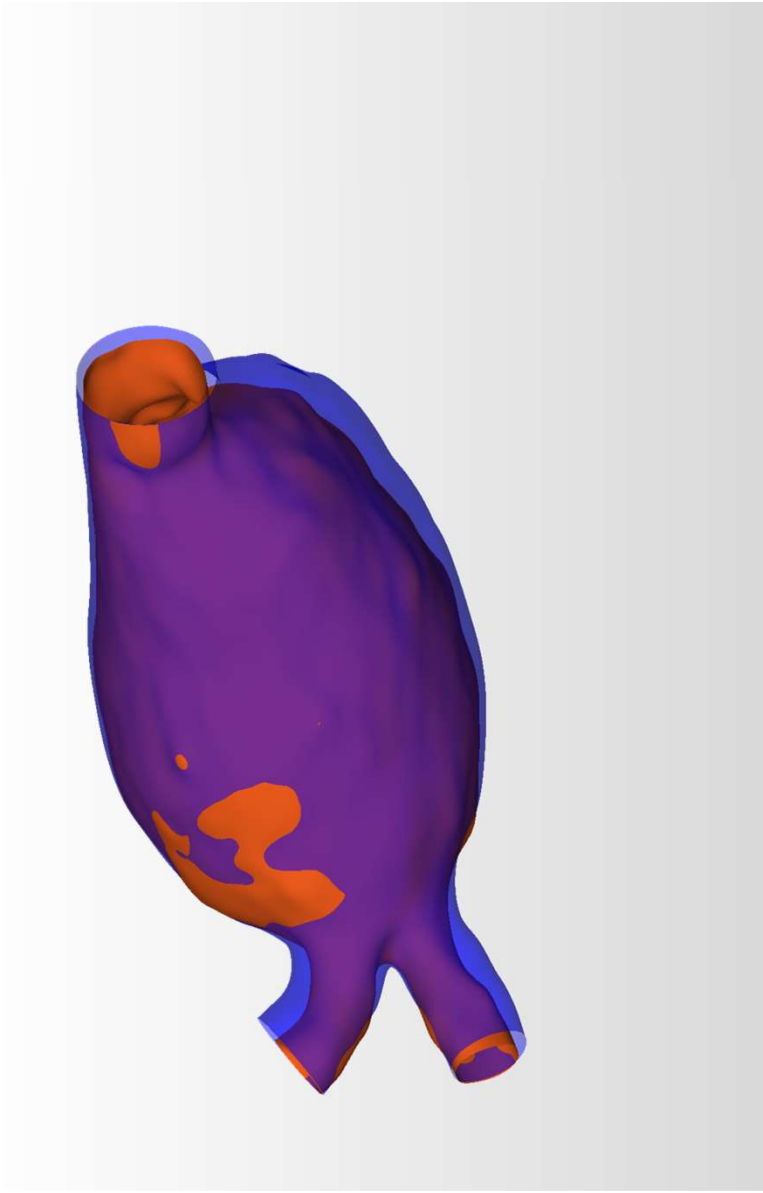




Geometric Variability

- **Isotopological mesh**

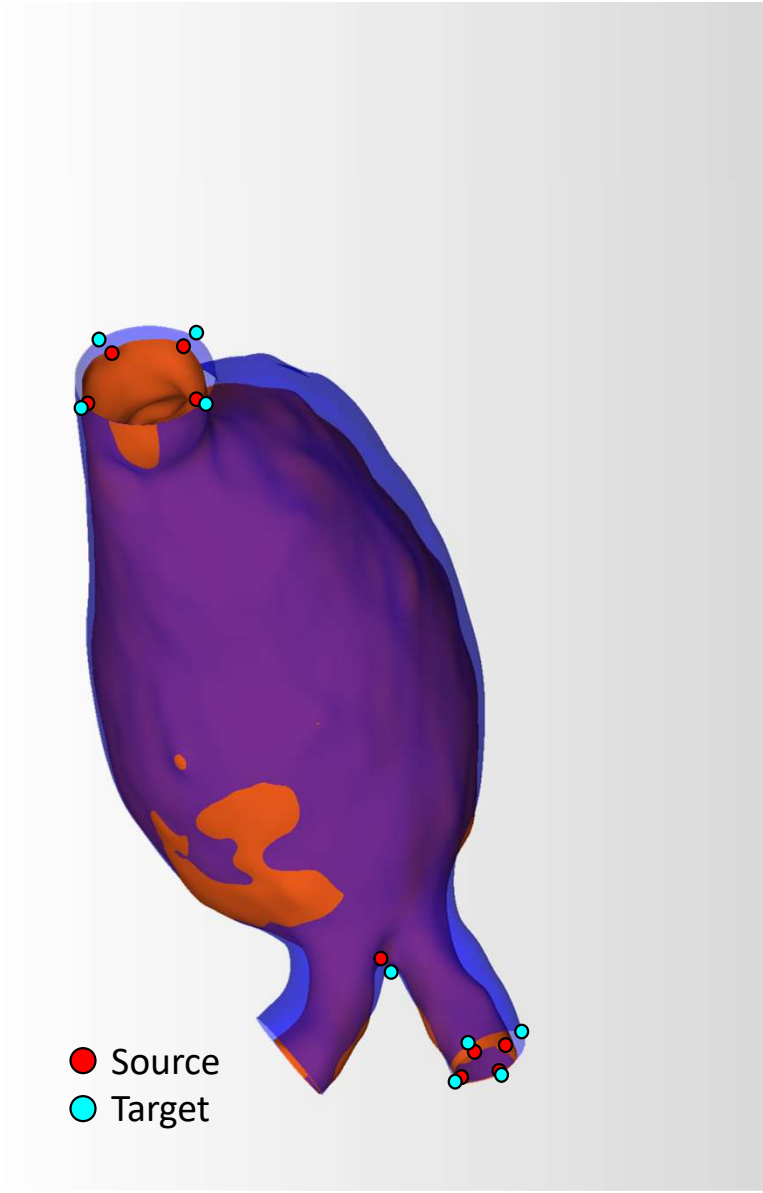
  Mesh morphing technique based on landmarks and projection using rbf™.



Geometric Variability

- **Isotopological mesh**

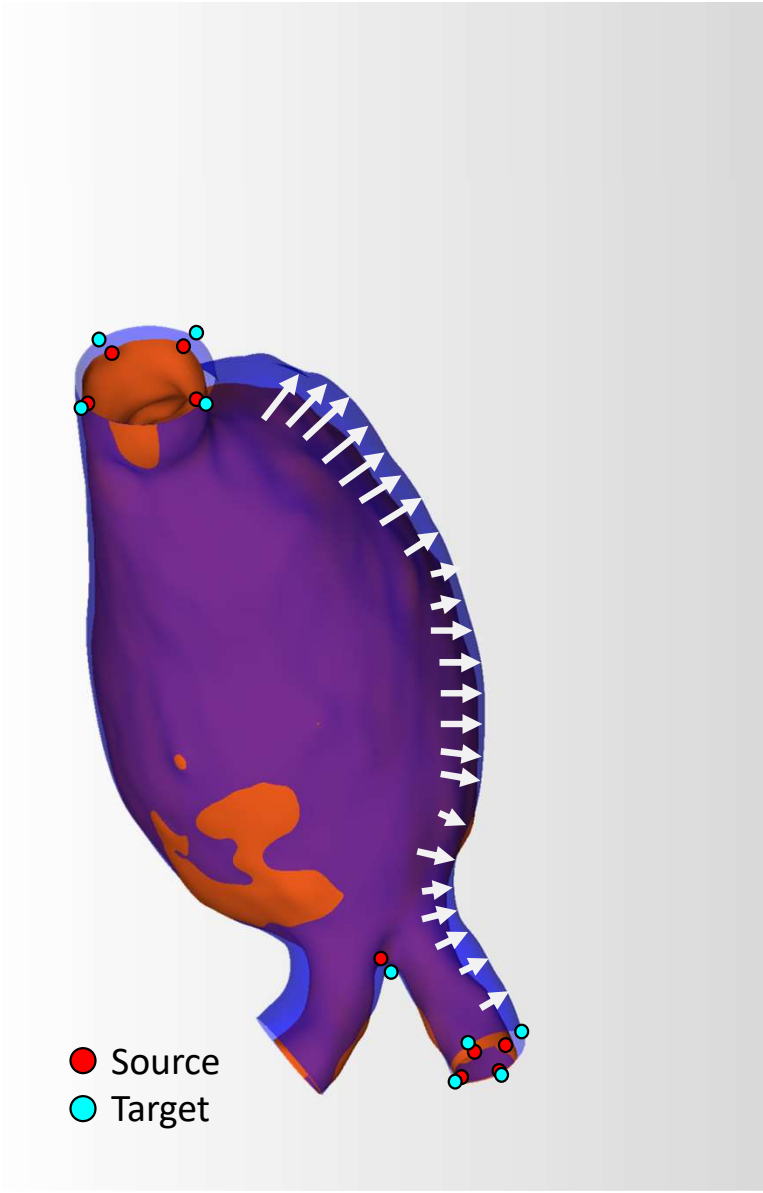
  Mesh morphing technique based on landmarks and projection using rbf™.



Geometric Variability

- **Isotopological mesh**

  Mesh morphing technique based on landmarks and projection using rbf™.

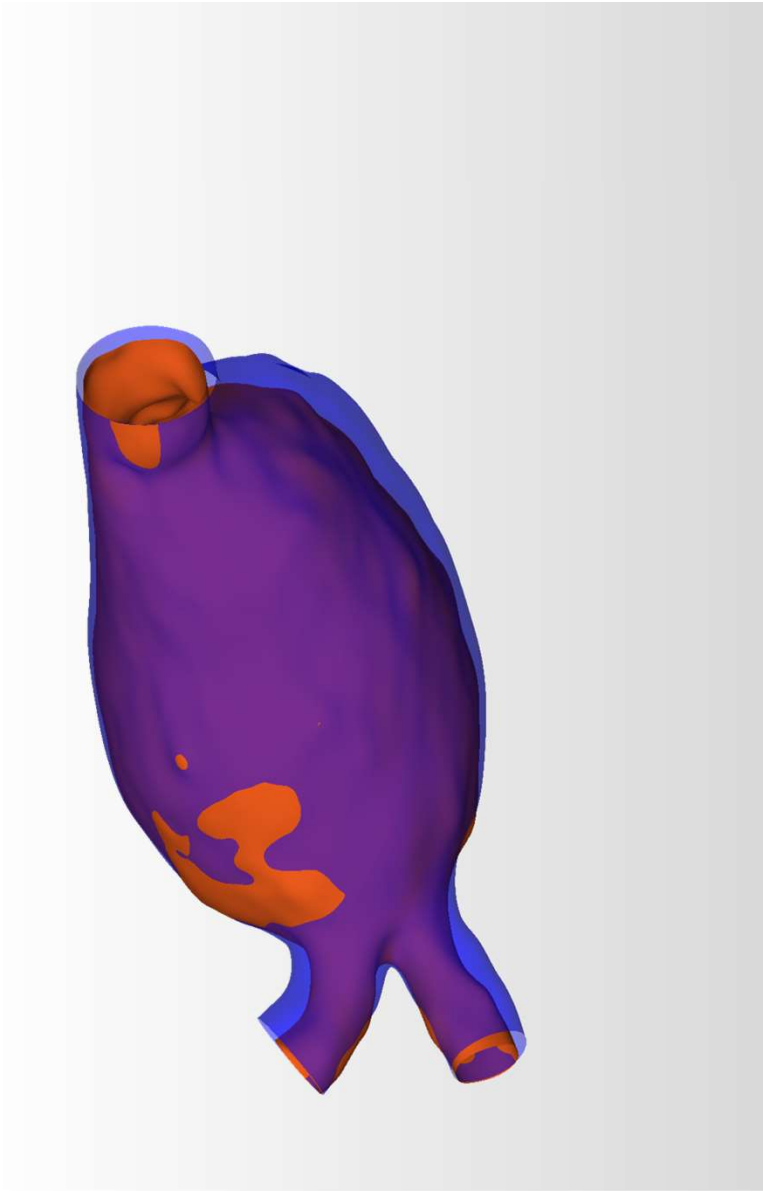


Geometric Variability

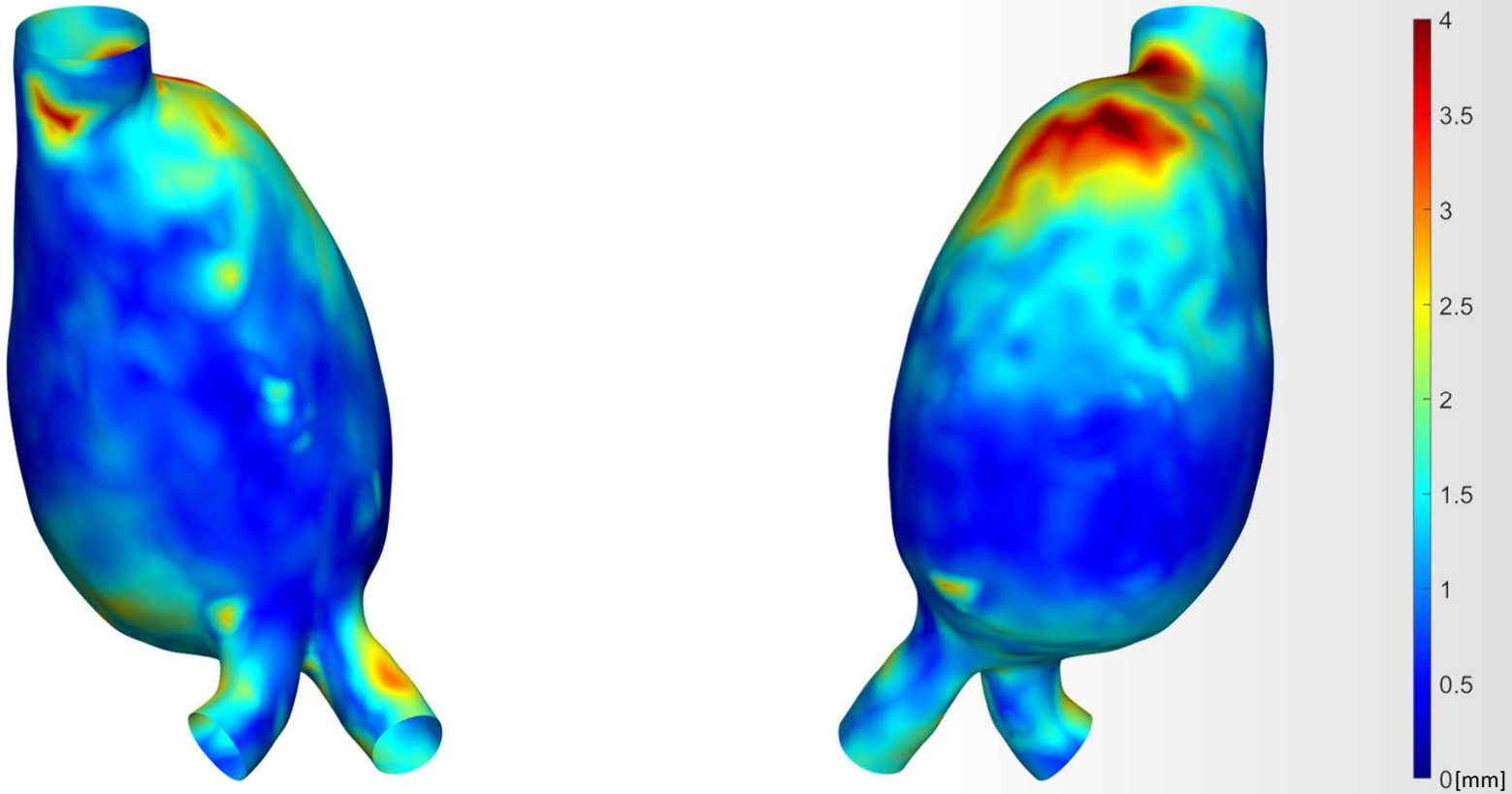
- **Isotopological mesh**

  Mesh morphing technique based on landmarks and projection using rbf.

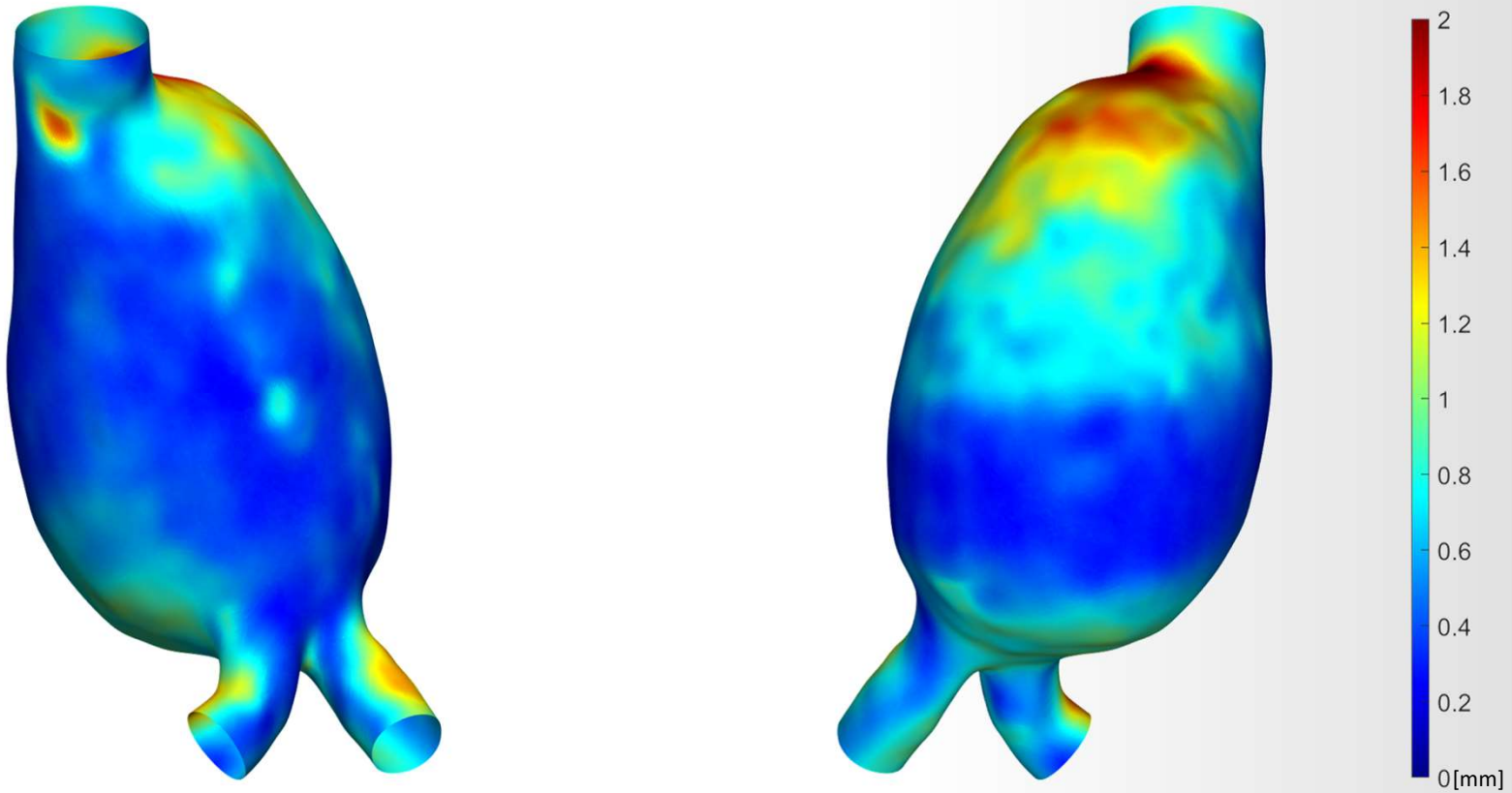
  - Maximum deviation
  - Standard deviation
  - Statistical Shape Model



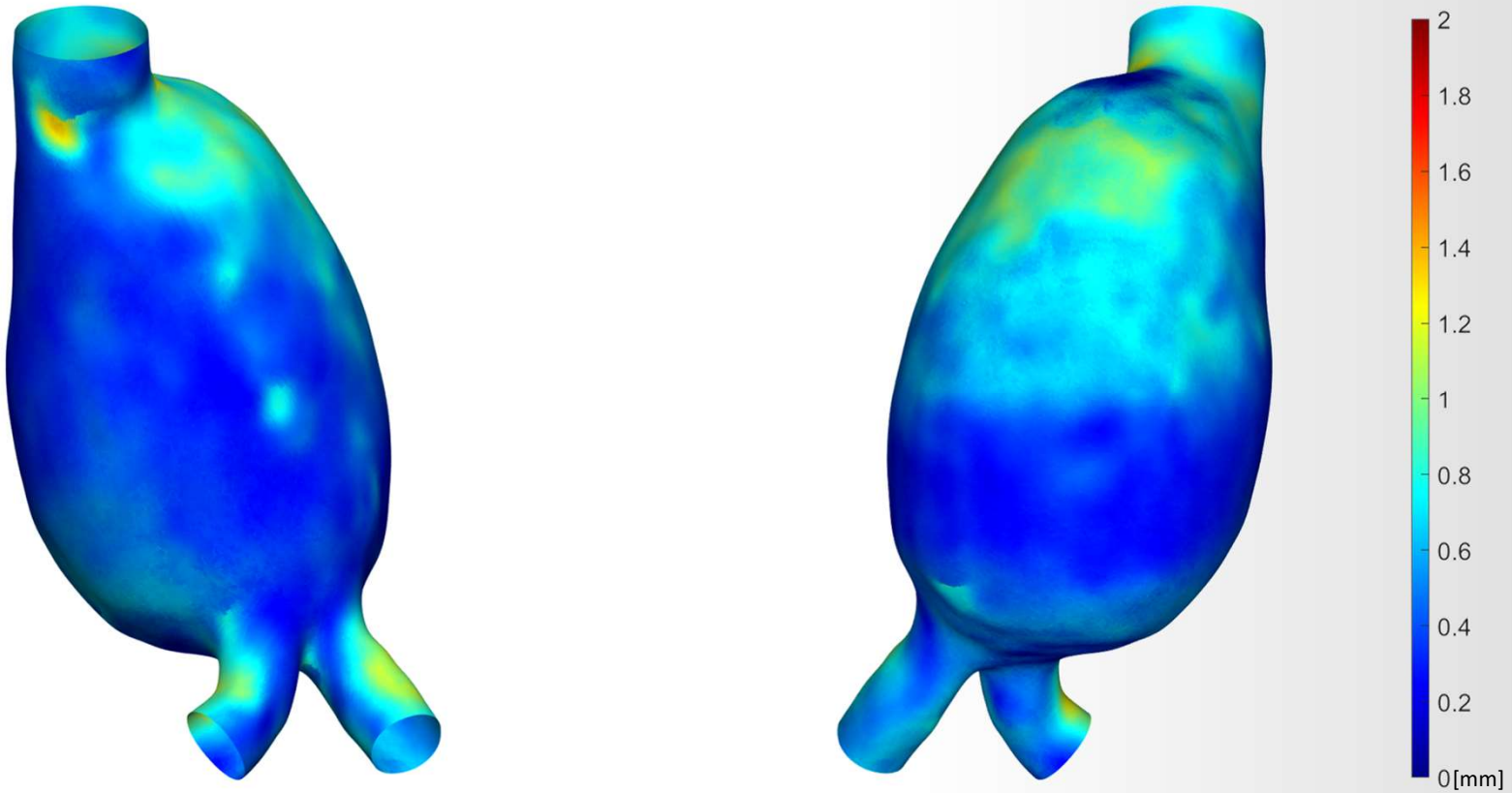
Geometric Variability: Maximum Deviation



Geometric Variability: Standard Deviation

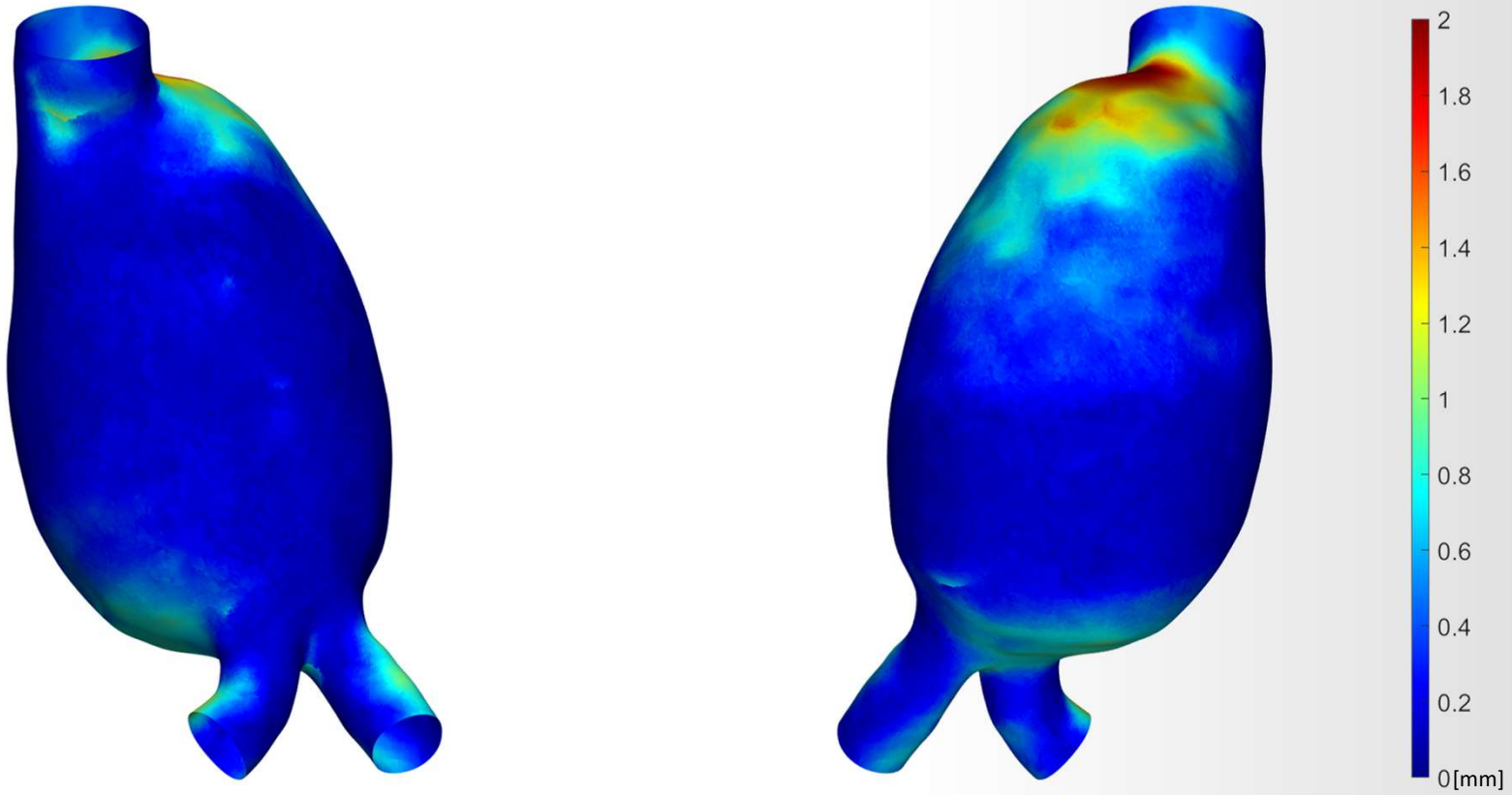


Geometric Variability: Standard Deviation XY



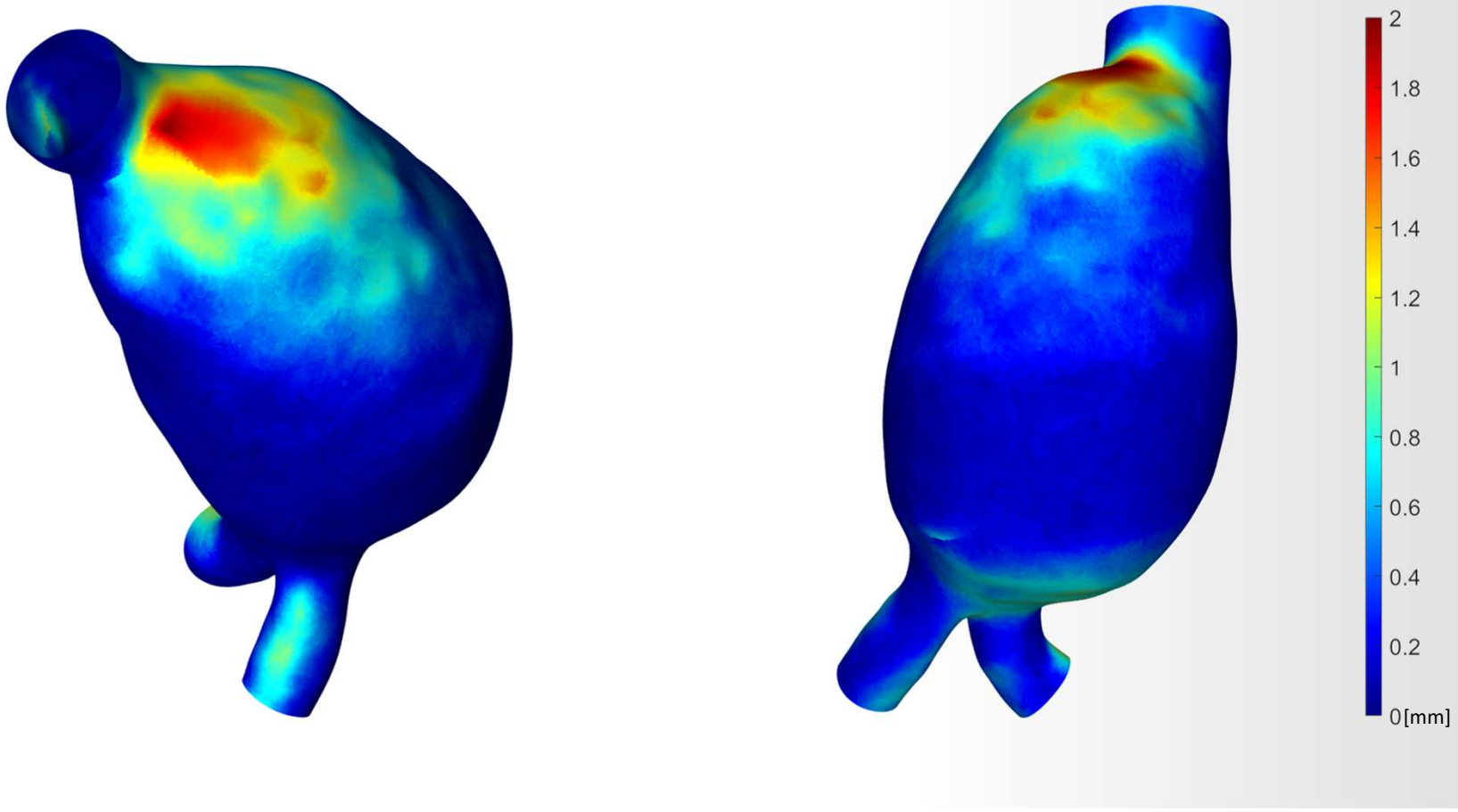
Geometric Variability: Standard Deviation Z

Voxel size = [0.824, 0.824, 2.5] mm



Geometric Variability: Standard Deviation Z

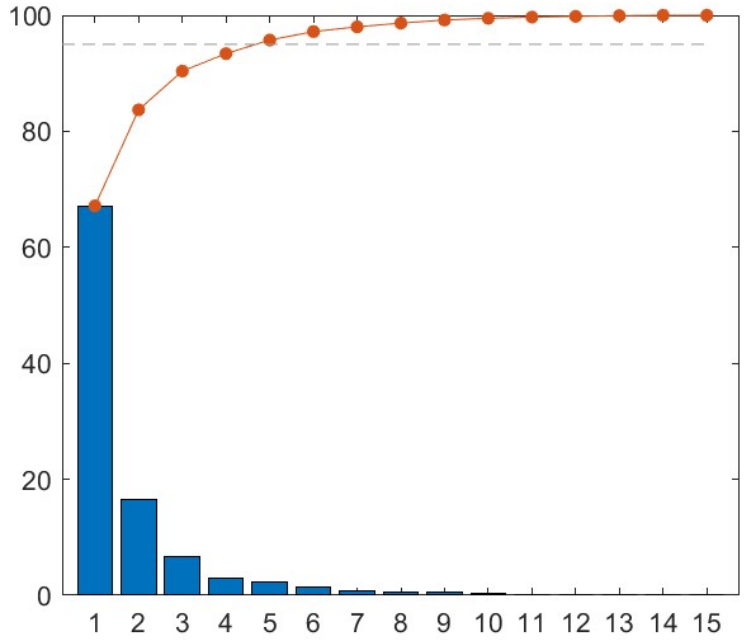
Voxel size = [0.824, 0.824, 2.5] mm



Geometric Variability: Statistical Shape Model

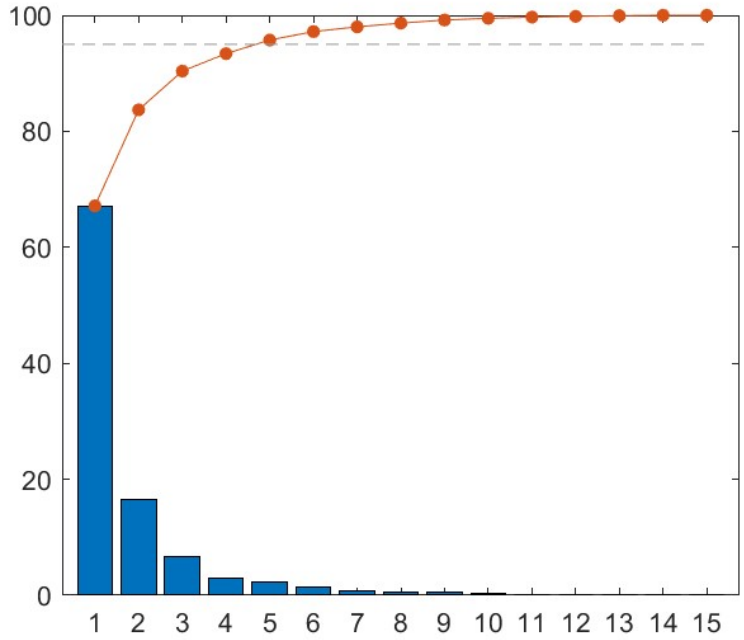
Geometric Variability: Statistical Shape Model

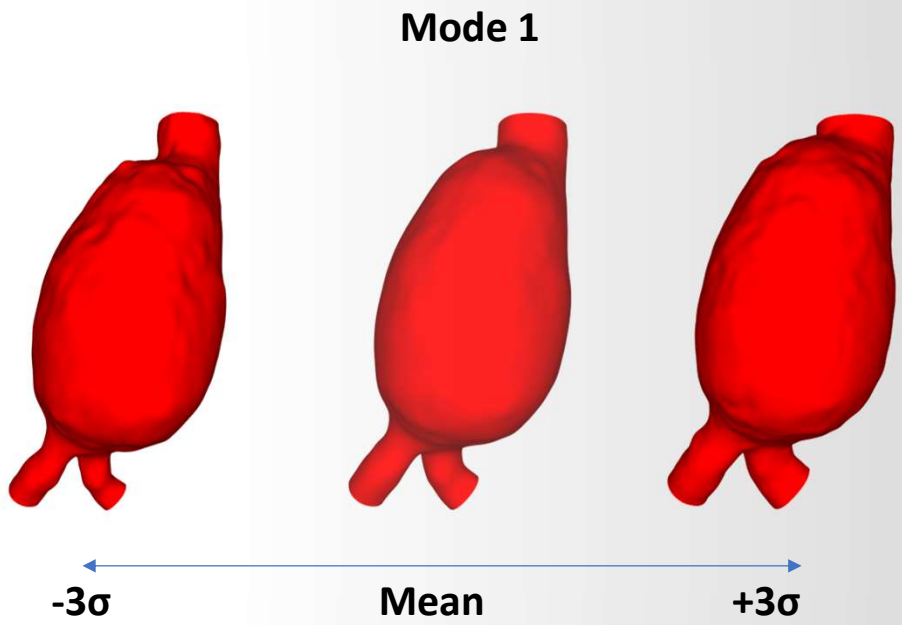
- With 5 modes we capture 95.7% of the variance



Geometric Variability: Statistical Shape Model

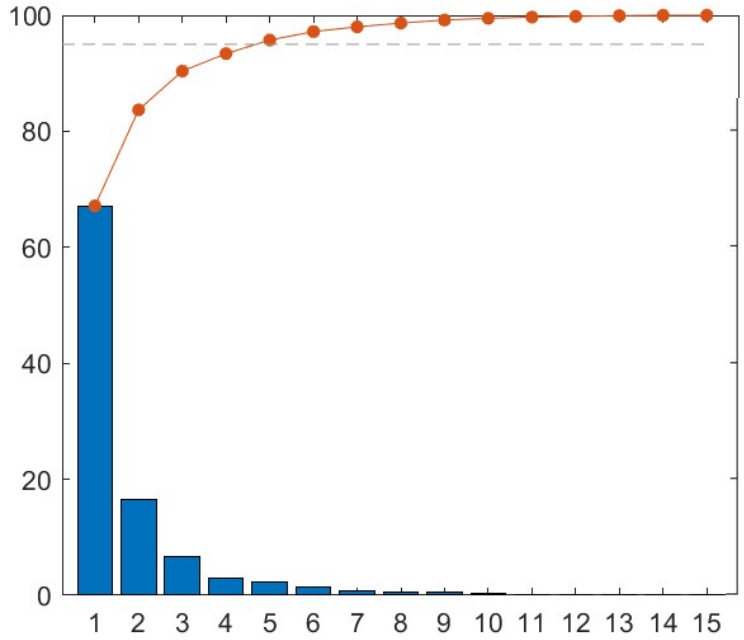
- With 5 modes we capture 95.7% of the variance



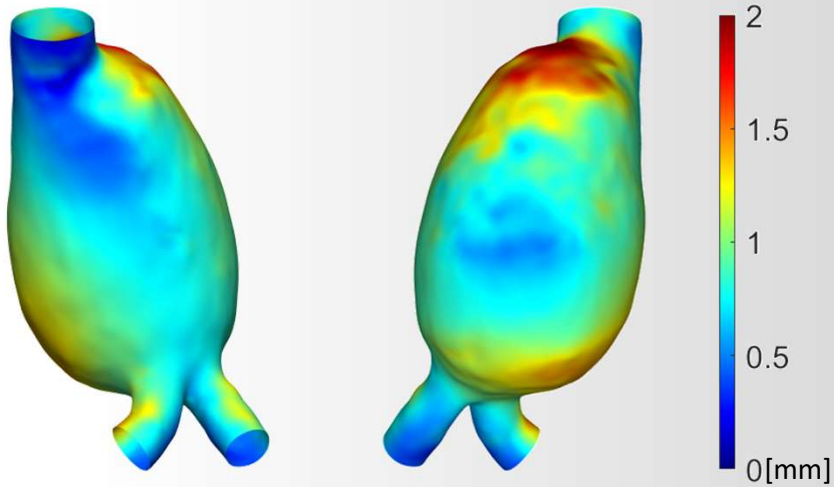


Geometric Variability: Statistical Shape Model

- With 5 modes we capture 95.7% of the variance



Mode 1
Displacements for 1σ



Hemodynamic Variability: Steady

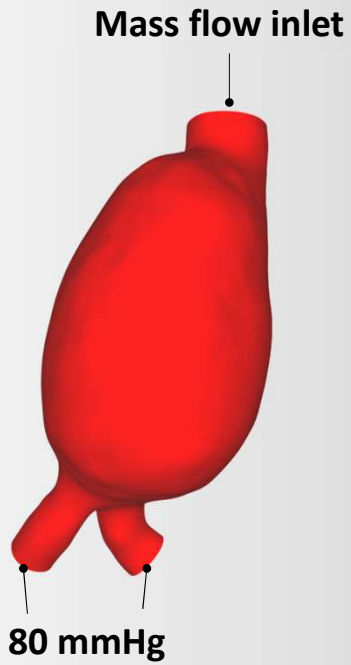
Hemodynamic Variability: Steady

Analysis of WSS, pressure drop, and outlet velocity

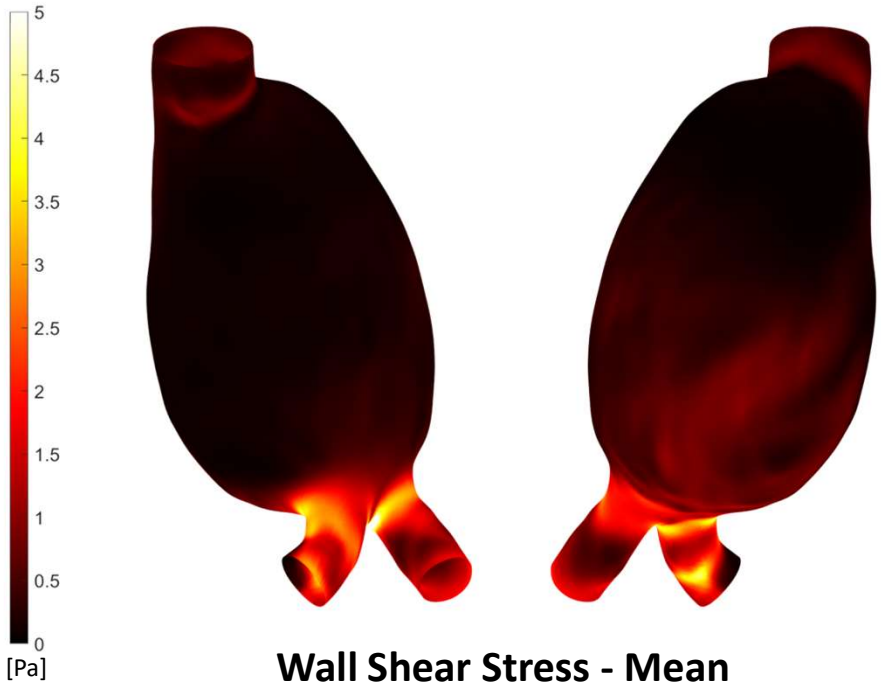
Setup:

- 3 steady state case: 50, 100 and 150 ml/s
- Outlet pressure = 80 mmHg
- Laminar
- Carreau non-newtonian fluid

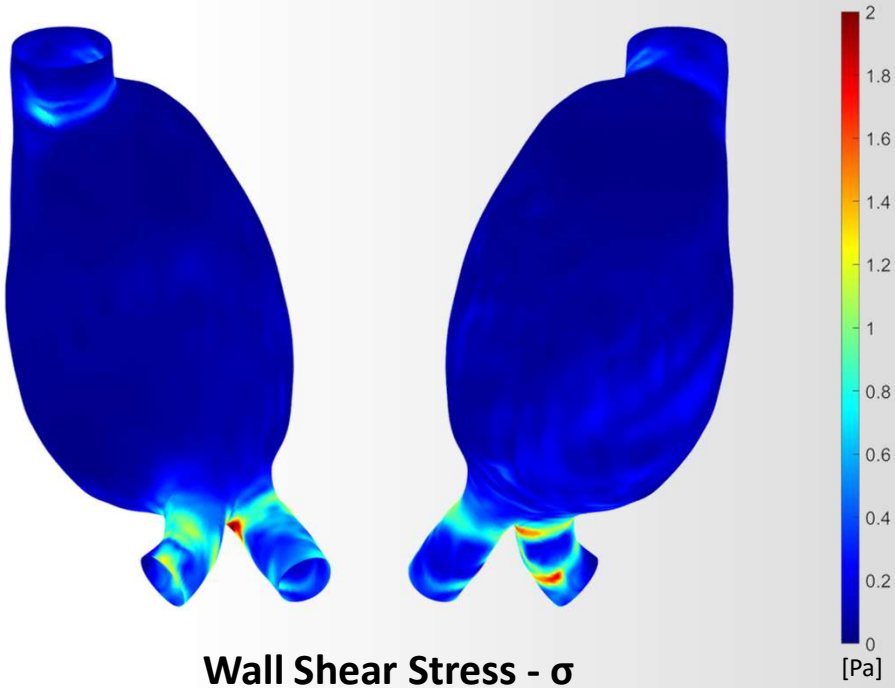
(ρ = 1056 kg/m^3,μ_∞=0.0035 Pa·s, μ_0=0.056 Pa·s, λ =3.313 s, n=0.3568)



Hemodynamic Variability: Steady 50 ml/s



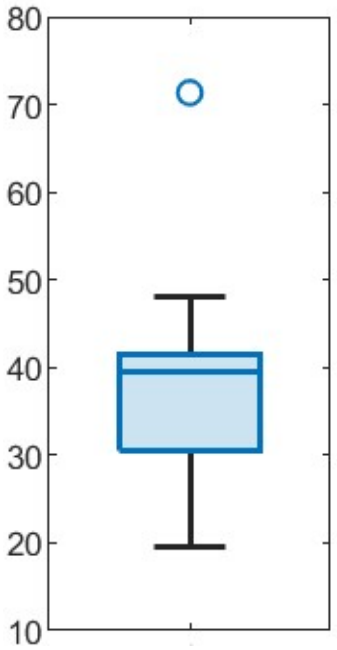
Wall Shear Stress - Mean



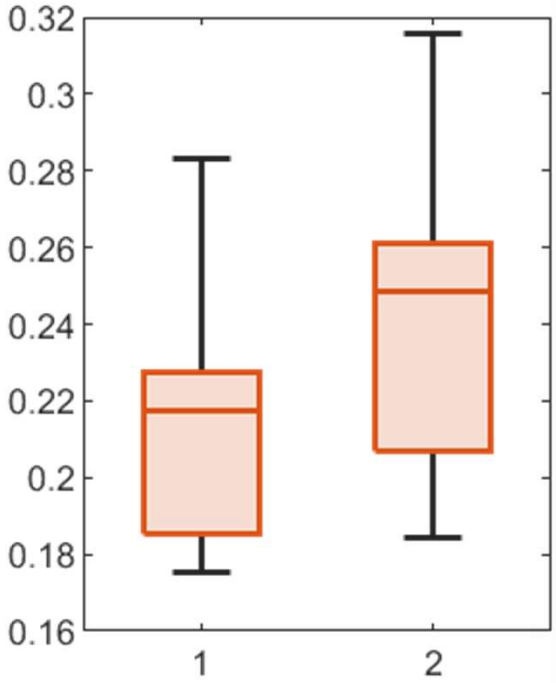
Wall Shear Stress - σ

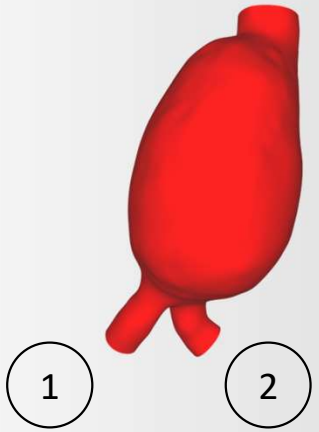
Hemodynamic Variability: Steady 50 ml/s

Pressure Drop [Pa]

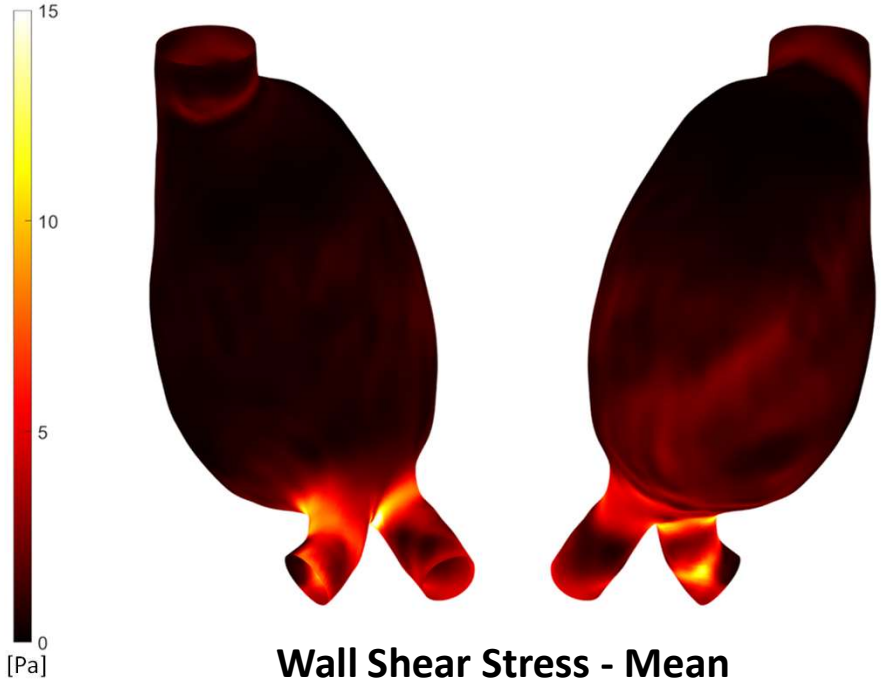


Outlet Velocity [m/s]

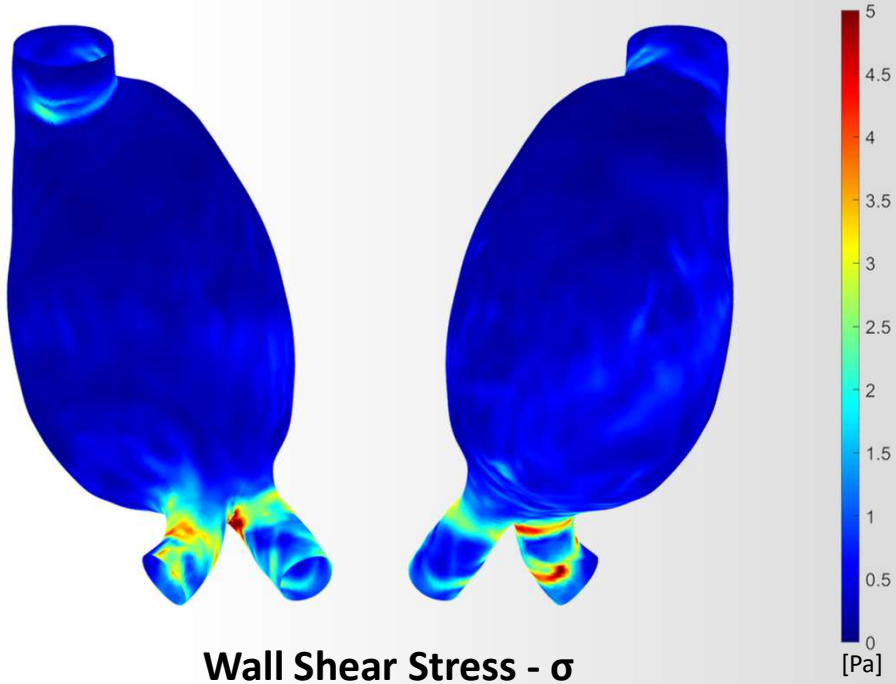




Hemodynamic Variability: Steady 100 ml/s



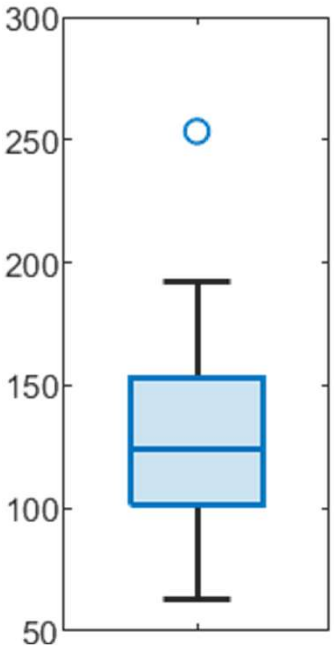
Wall Shear Stress - Mean



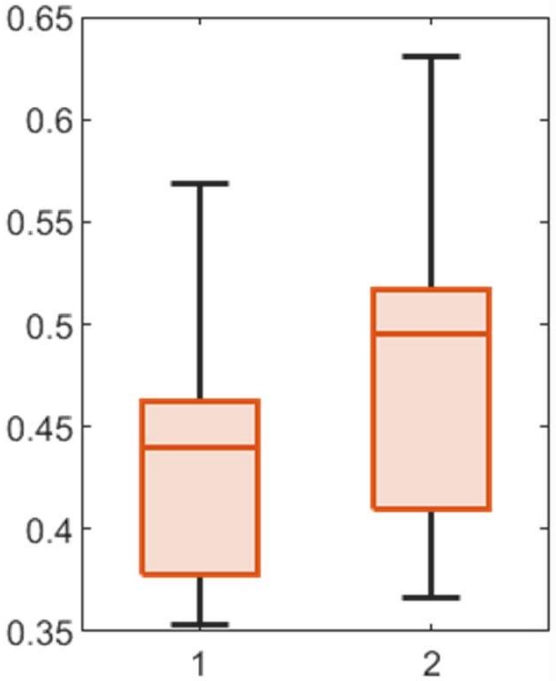
Wall Shear Stress - σ

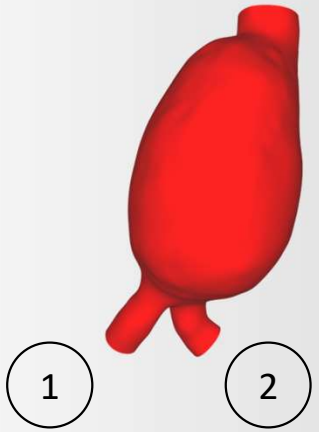
Hemodynamic Variability: Steady 100 ml/s

Pressure Drop [Pa]

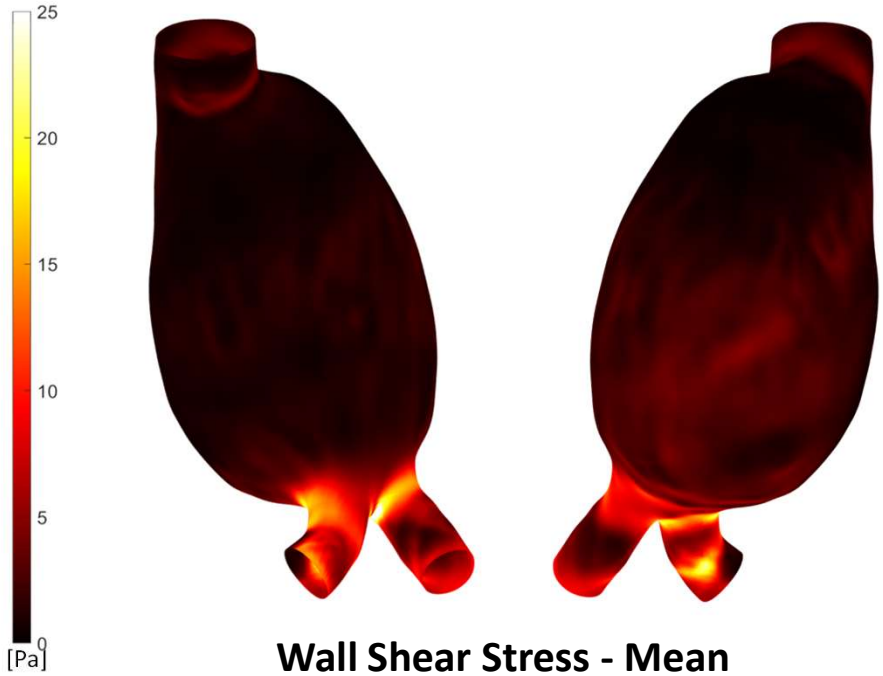


Outlet Velocity [m/s]

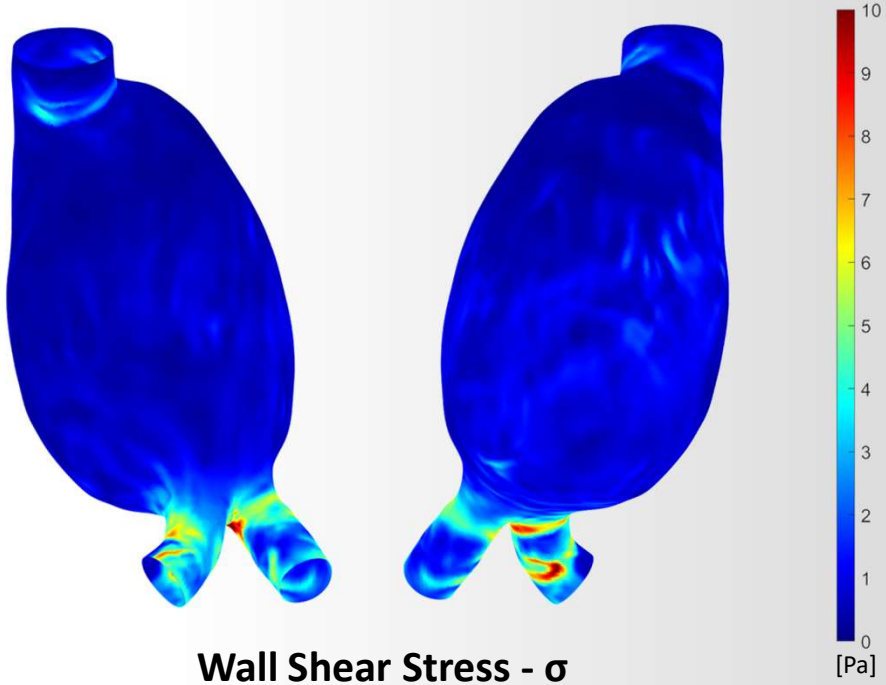




Hemodynamic Variability: Steady 150 ml/s



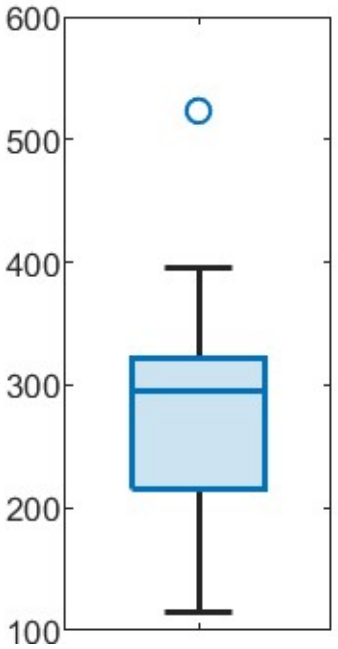
Wall Shear Stress - Mean



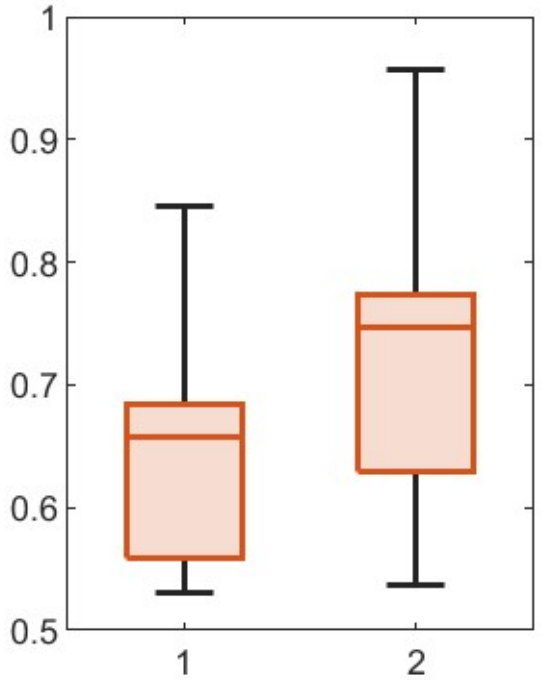
Wall Shear Stress - σ

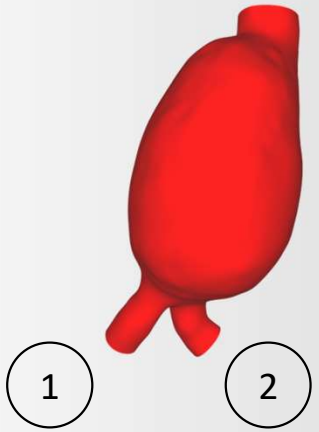
Hemodynamic Variability: Steady 150 ml/s

Pressure Drop [Pa]



Outlet Velocity [m/s]





Hemodynamic Variability: Transient

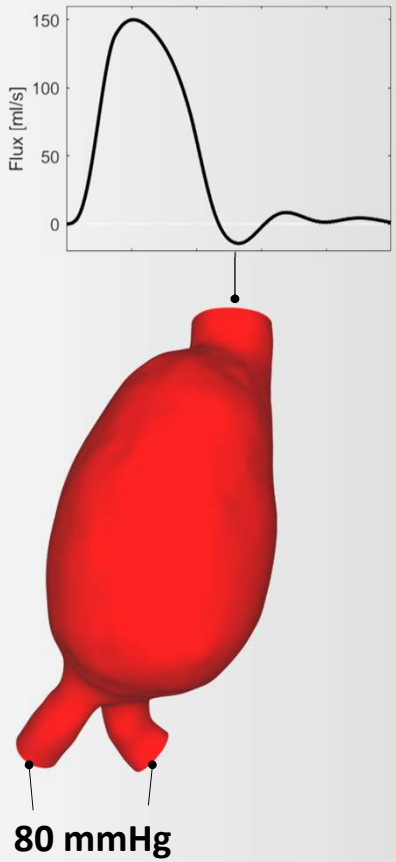
Hemodynamic Variability: Transient

Analysis of TAWSS, OSI, pressure drop, and outlet flux.

Setup:

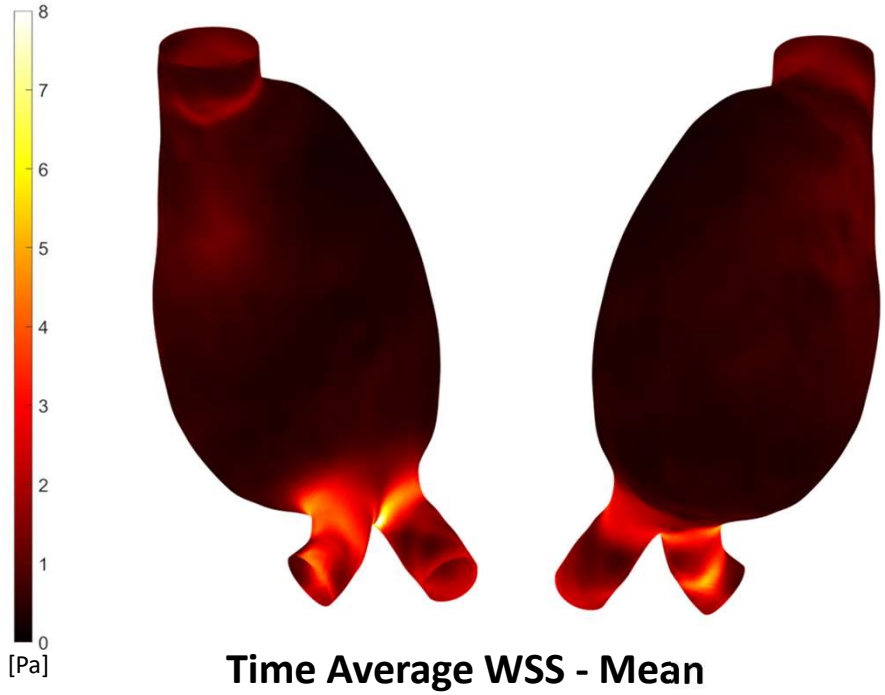
- Inlet: imposed mass flow profile
- Outlet pressure constant = 80 mmHg
- Laminar
- Carreau non-newtonian fluid:

  (ρ = 1056 kg/m^3,μ_∞ =0.0035 Pa·s, μ_0 =0.056 Pa·s, λ =3.313 s, n=0.3568)
- 4 cardiac cycles

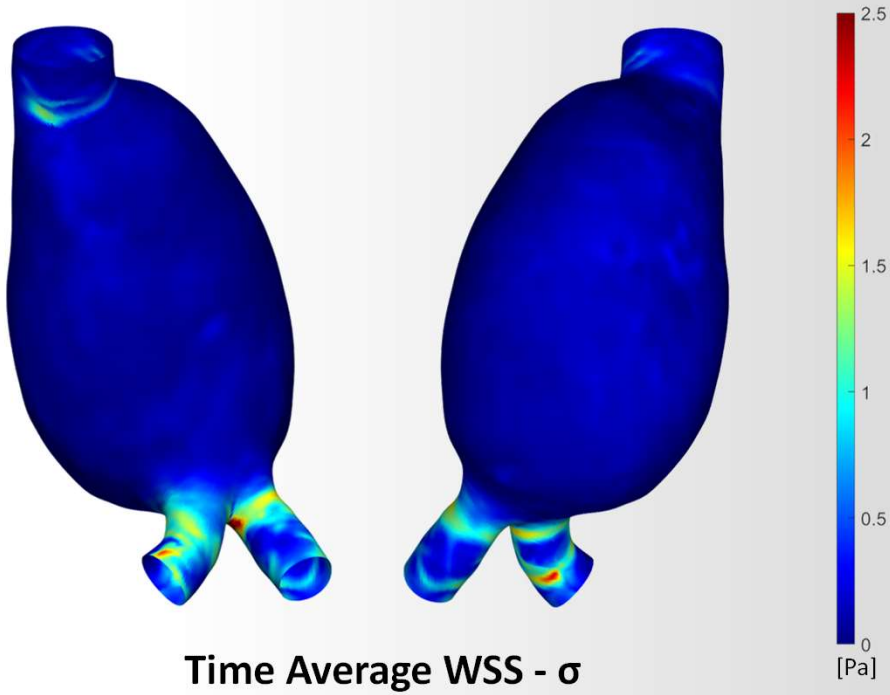


Hemodynamic Variability: Transient

$$\mathrm{TAWSS} = \frac{1}{T}\int_0^T |\mathrm{WSS}|dt$$



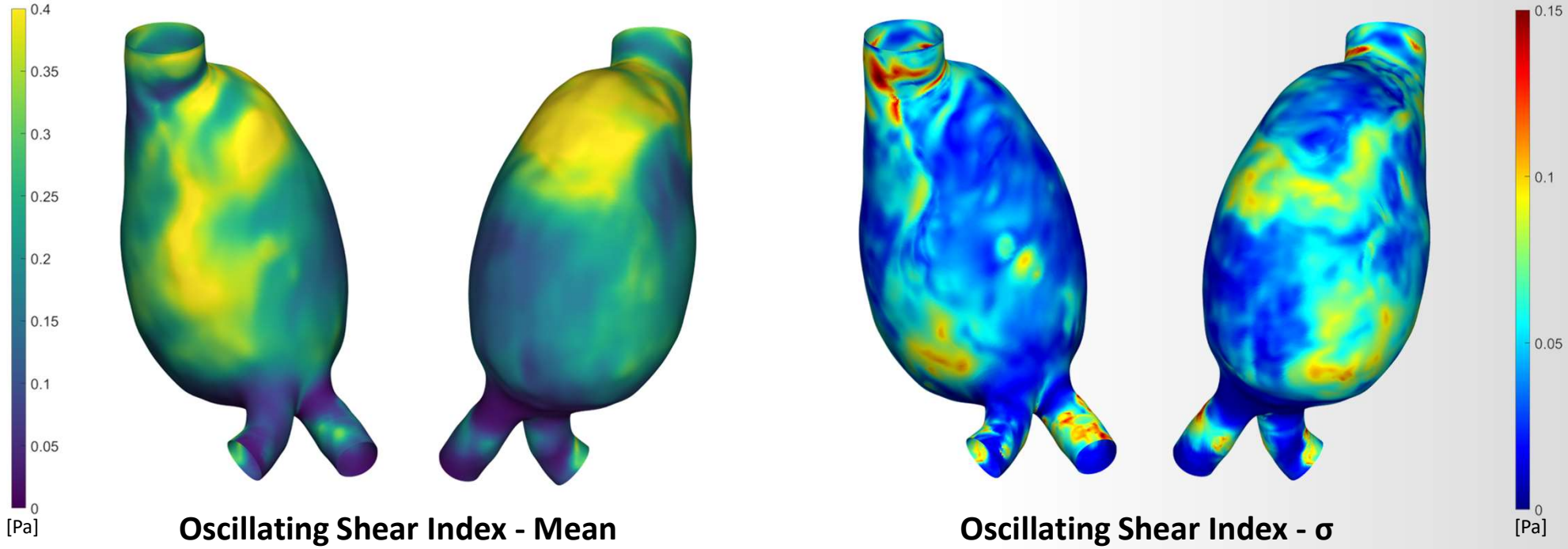
Time Average WSS - Mean



Time Average WSS - σ

Hemodynamic Variability: Transient

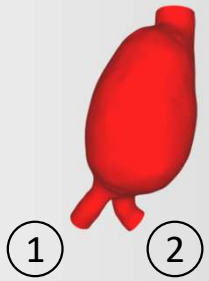
$$\mathrm{OSI} = 0.5\left(1 - \frac{\left|\int_0^T \mathrm{WSS}dt\right|}{\int_0^T |\mathrm{WSS}|dt}\right)$$



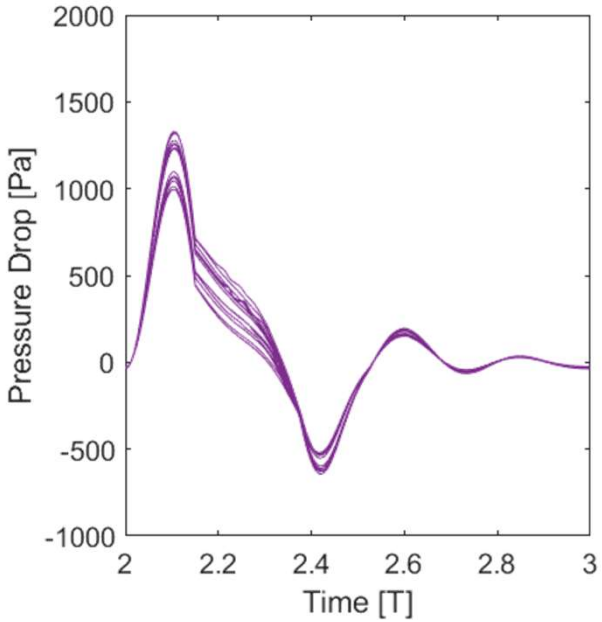
Oscillating Shear Index - Mean

Oscillating Shear Index - σ

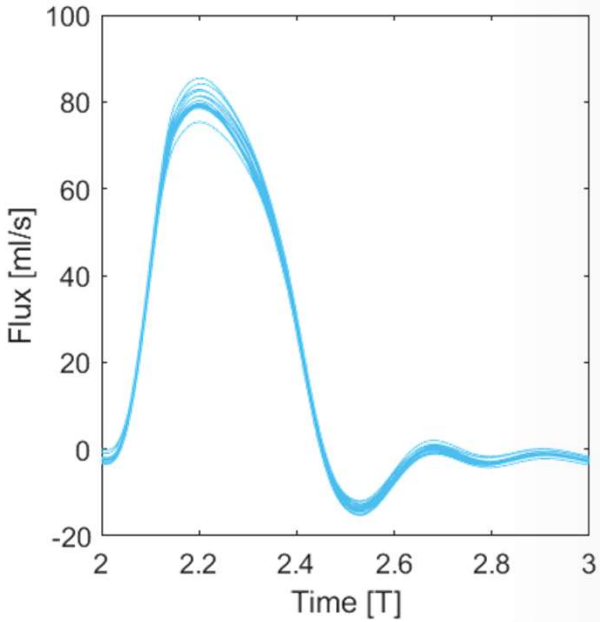
Hemodynamic Variability: Transient



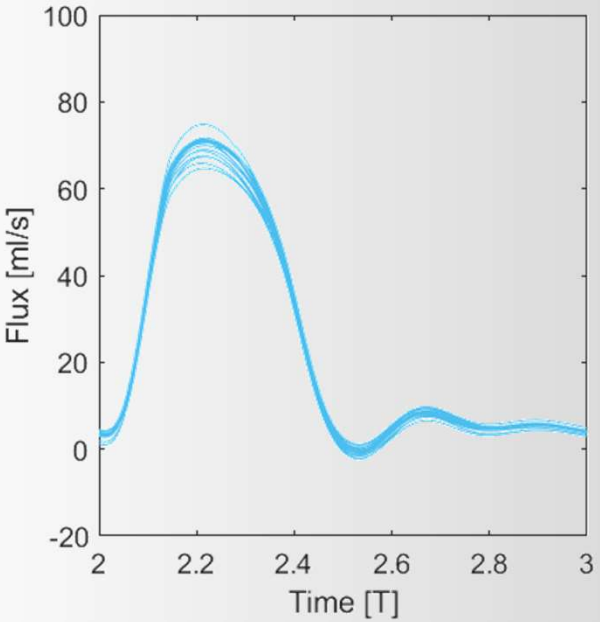
Pressure Drop



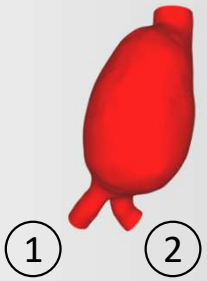
Outlet Flux 1



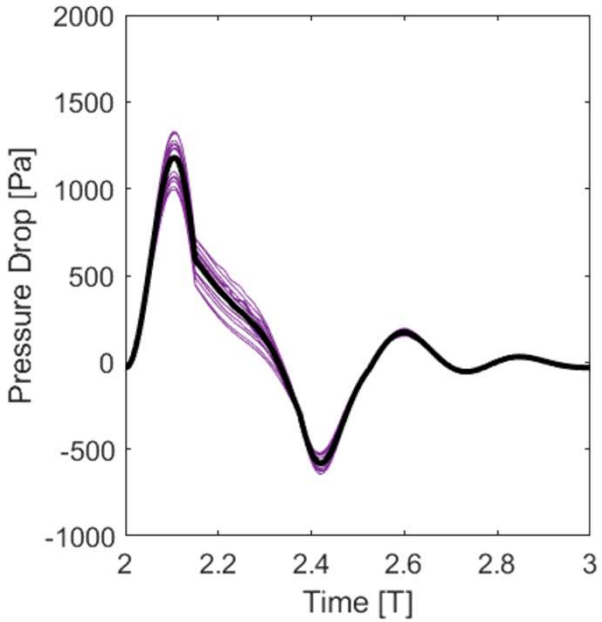
Outlet Flux 2



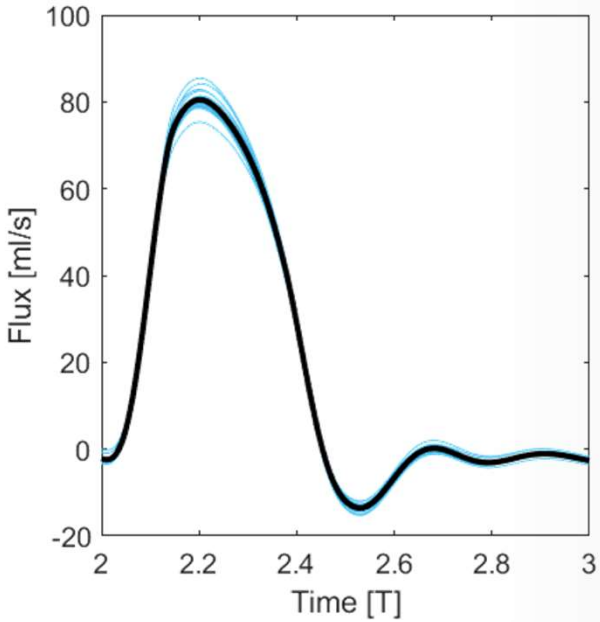
Hemodynamic Variability: Transient



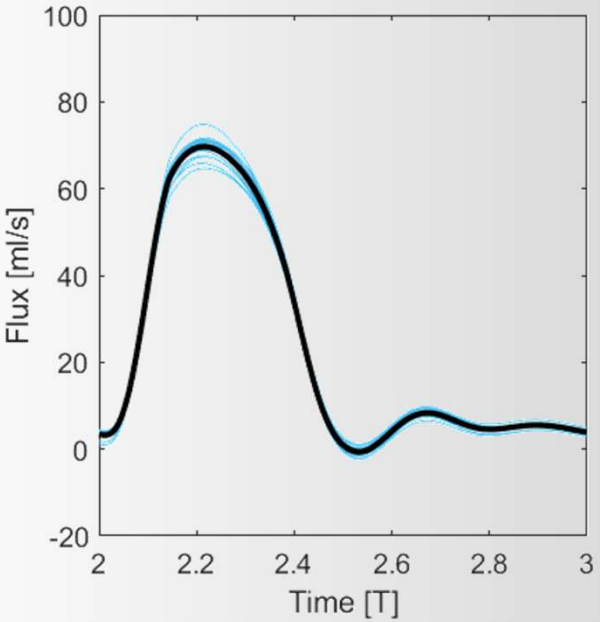
Pressure Drop



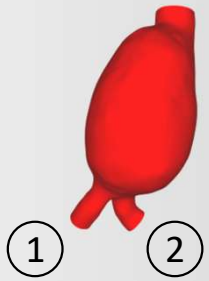
Outlet Flux 1



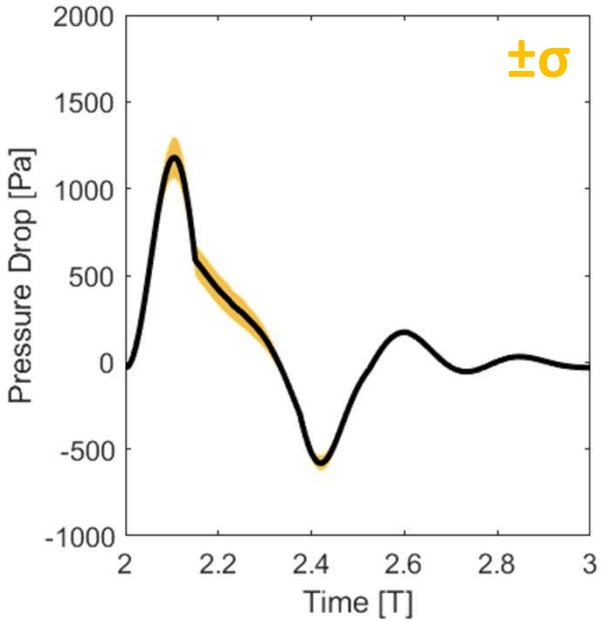
Outlet Flux 2



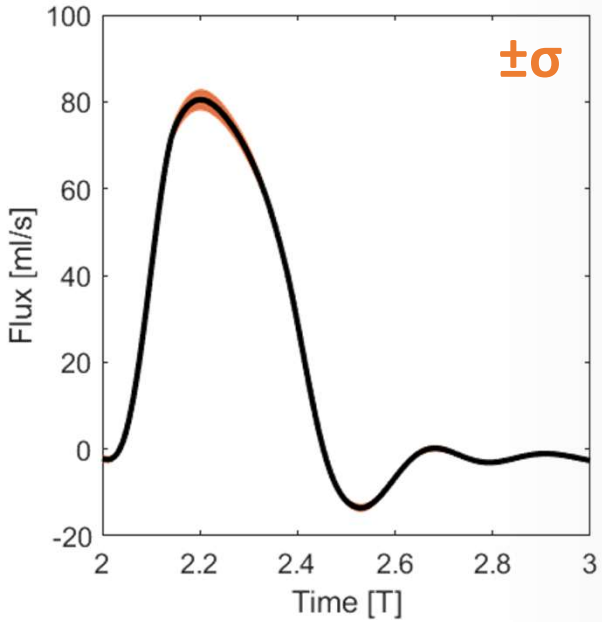
Hemodynamic Variability: Transient



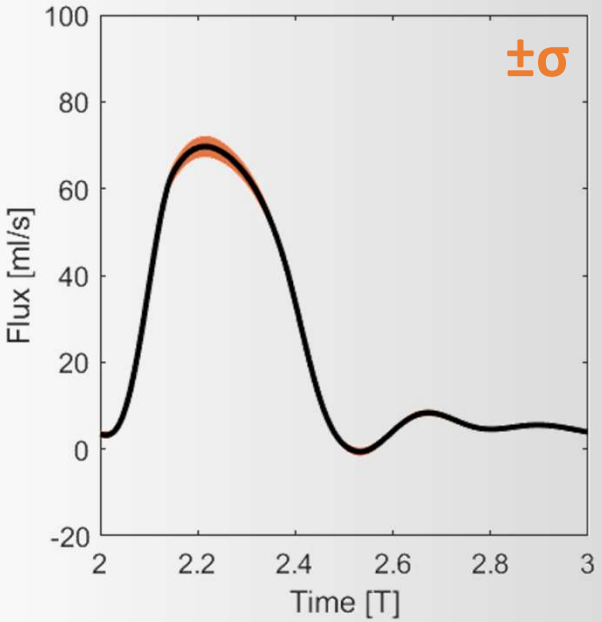
Pressure Drop



Outlet Flux 1



Outlet Flux 2



Future Works

- Combined analysis of volume segmentation variability and MRI flux variability
- Effect of smoothing
- Comparision of segmentation methods: manual, semi-automatic, automatic
- FSI

Acknowledgments

Daan Jongerius
Leonardo Geronzi
Eirini Kardampiki
Marc Horner
Marco E. Biancolini

Antonio Martinez Pascual
antonio.martinez@uniroma2.it

MeDiTaTe Project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 859836

Thank you!